TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

MECHANICAL ENGINEERS

1930

VOL. 52—PART II

MAN-WDI

PUBLISHED BY
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
29 WEST THIRTY-NINTH STREET, NEW YORK, N. Y.

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Printed in the United States of America by
The Mack Printing Co., Easton, Pa.

Foreword

VOLUME 52 of the TRANSACTIONS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS contains 35 individual sections published during 1930 under the sponsorship of the Society's 15 professional divisions, as well as its annual Record and Index. The technical papers and reports that make up this volume represent the Society's annual contribution to the permanent record of mechanical-engineering achievement. Most of these papers and reports were presented at meetings of the Society and of its professional divisions and local sections. Other papers published by the Society but not included in the Transactions may be located by means of the Record and Index which forms a part of this volume.

The papers published in this volume were issued originally in pamphlet form. These pamphlets appear in sections, each section being sponsored by one of the Society's professional divisions. A member of the Society may register in any three of the fifteen professional divisions and receives in pamphlet form as they are issued the sections of Transactions sponsored by those divisions.

All sections of the Transactions are bound together at the end of the year for the convenience of libraries and of engineers who wish all of the papers in permanent form. Copies of the bound Transactions will be found in depositories located in selected engineering, university, and public libraries throughout the world. A complete list of these depositories will be found on page 97 of the Record and Index. Copies of the bound Transactions have also been set aside for sale.

At the end of Volume 52 will be found the Record and Index of the A.S.M.E. for 1930. This is the permanent record of the Society's activities for the year, and includes lists of committees, reports of meetings and committee activities, and memorial notices of deceased members. The indexes include those of special publications, and of *Mechanical Engineering*. Printing of the Record and Index in this form was ordered by the Council of the Society, and returns to the Transactions material of permanent historical value which has been issued for the past three years (1927–1929) as a separate publication.

NUMBERING AND ARRANGEMENT OF PAPERS IN COMPLETE TRANSACTIONS

In this volume the papers of each section are grouped together and are numbered serially. The different sections follow each other alphabetically. Each paper is designated by a symbol composed of key letters followed by the volume number and paper number. The letters refer to the section of the Transactions to which the paper is assigned. Thus AER refers to the Aeronautic section, IS to the Iron and Steel section, etc. Each of the two books forming parts I and II of Volume 52 contains a complete index of subjects, authors, and discussers to both parts of the volume so that either may be consulted. The arrangement of the index and designations for locating material are explained at the beginning of the index.

CONCERNING BLANK PAGES

The papers in each section of the Transactions are printed separately so that they may be available as reprints. This makes it necessary to print each paper so that the number of pages is a multiple of four. Because of this, blank pages will be found at the ends of papers which do not completely fill the printer's form.

THE PUBLICATIONS COMMITTEE.

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Progress in Industrial Management

Contributed by the Management Division

Executive Committee: W. L. Conrad, *Chairman*, Robt. E. Newcomb, *Vice-Chairman*, G. W. Kelsey, *Secretary*, C. E. Hagemann, Wm. B. Ferguson, and Chas. W. Lytle

WITH the nation-wide interest shown by business men in the problems of "waste in industry" has come a steadily increasing effort toward the elimination of this waste and the introduction of methods of managerial control in industry. As the manufacturers, distributors, and consumers have studied existing waste of time, material, and human energy in our productive and distributive processes, their sense of responsibility for the waste, its causes, and its correction has resulted in a determined effort for its elimination. Not only have these industrial interests asked and received cooperation from one another, but they have also appealed to the Department of Commerce, Chamber of Commerce of the United States, and professional societies for cooperation.

This cooperative effort has helped to reduce inventories and idle investment, to increase the turnover of inventories, to increase sales volume, to reduce manufacturing and selling costs, to increase profits and values, and to improve quality and service. The success of the simplification movement has stimulated interest in standardization of grade and quality of products; and has advanced materially the development of specifications, particularly the more general use of specifications in buying.

The elimination of waste in industry is taking a new turn. It is now realized that, besides the waste of concrete materials resulting from overdiversification and other causes, there is a tremendous waste through the use of inefficient processes for the production, transmission, and utilization of energy.

The history of the recommendations made by the many agencies that have studied the problem of managerial control, shows many good examples of that flexibility which enables the simplified-practice recommendation of any industry to keep pace with changing consumer demand. Adding items as new developments require and discarding the obsolete have a stabilizing influence to retard any rapid increase of unnecessary diversification such as frequently takes place in an industry that has no definite program of simplification. Manufacturers have justly benefited through fewer interruptions for adjusting machinery, the release of unproductive space for other purposes, etc.

The interest that has been manifest in managerial control in industry during the past few years, and especially the searching investigation that the financial institutions now make into an industry before they agree to any proposed expansion of that industry, or to the expenditure of any considerable amount of capital, shows conclusively that more attention is being given to managerial control than was formerly the case. Continuation of this practice augurs well for the future of all industries.

Another tendency which is becoming manifest is the realization that conservation and efficient utilization of resources apply to man-made as well as to natural resources. So much capital is now tied up in our great industries, and so many people are dependent upon them, that it is no longer possible to scrap an entire industry because science has developed a new product to replace the one which that industry turns out. The complete abandonment of certain facilities in favor of others without careful study will not occur so often in the future as it has in the past. The almost complete overthrow of our highway and waterway systems by the railroads, in the end proved an economic blunder. We know now that research could have coordinated them with tremendous savings. The railroads have learned a lesson, and the result is the present effort to coordinate rail, highway, and aerial transportation facilities, with the hope of producing a unified and efficient system.

Managerial Control in Industry

With the demand for economy increasing until it has become a most important factor in the onrush of industry, little is wasted nowadays. Profitable business enterprises are built upon by-products and materials that once were thrown into the discard. No longer are sawdust, waste oils, scrap iron, and miscellaneous factory débris cast aside to be forgotten.

The report of the Committee on Recent Economic Changes says in reference to managerial control in industry:

> The chapter of this report on industrial management prepared for the committee, presents the results of analysis of 100 fair samples of normally successful established business institutions, so chosen as to show prevailing practices. This chapter shows that more men are being brought within managerial responsibilities and that the "big boss" is passing. There is today not only more production per man, more wages per man, and more horsepower per man, but more management per man as well.

The increasing introduction of scientific management methods in America, the intensive competition, and the increasing importance of the control of details for desired profit is making the importance of detailed managerial control through thermometrical budget and cost information more and more important. Budgets and the actual performance in conformity show the greatest progress.

The improved and wider usage of budget systems is a definite step of management progress, and is bringing about greater detailed and intelligent coordination between production and distribution.

The effort toward waste elimination in America is probably doing more to advance managerial control and increase profits than any other single element, since it compels detailed study of operation.

Better Management

"There are greater profits through better management, as revealed through simplification, the elimination of waste, more highly efficient personnel, and a finer spirit of cooperation," said Craig B. Hazelwood, vice-president of the Union Trust Company of Chicago, in a recent article. In this article Mr. Hazelwood stated that "the amazing spectacle of the youngest of nations in the vanguard of commercial progress pays silent tribute to the creative genius which has so distinguished American business." Continuing, he said;

> In the face of this remarkable development it is natural, but unfortunate, that the emphasis be placed upon size and volume, attributes which can never measure up as the ultimate aim of industry. In the fast-running current of these days, we need to take a new grip upon the practical realities of business, realizing that though we set up the greatest retail business, the largest factor, the biggest jobbing organization in the country and have not profits we have failed to be of permanent service to the public. Fortunately, we are now in the

morning hours of a new era in scientific management, revealed through simplification, the elimination of waste, more highly efficient personnel, and a finer spirit of cooperation.

Ethical Standards

The most outstanding contribution of the year in the field of industrial literature is the two-volume report entitled "Recent Economic Changes," issued by the National Bureau of Economic Research. This is an outcome of the President's Conference on Unemployment and is a most searching study. Every conceivable phase of industry is covered and the very best information is made available regarding all of the important trends. Much stress is placed on the social efforts of our greater productivity. Greater earnings and shorter hours together have increased the demand for goods, and this demand is by no means restricted to necessities. To quote briefly: "The survey has proved conclusively what has long been held theoretically to be true, that wants are almost insatiable—that one want satisfied makes way for another. The conclusion is that economically we have a boundless field before us, that there are new wants which will make way endlessly for newer wants as fast as they are satisfied."

The connection between scientific research and industrial management is more direct than might at first be imagined. The development of new and improved materials and of better and more economical processes has a profound influence on management methods.

The past year has shown an increasing realization of the fact that management can be truly efficient only if the thing managed is efficient in itself. The efficient management of a horse-drawn dray will not result in lowering the cost of transportation to that by motor truck. Industrial managers are looking more and more deeply into the equipment and processes employed in their plants to make sure that they are the best for each particular purpose. Often the manager is able to see chances for improvement which might be overlooked by those more directly concerned with the actual mechanics of the business.

Wage Incentives

For some time a tendency has been developing to make more and more group applications of incentive plans. This is a natural accompanyment of mass production in that more and more work is interdependent. As in all new things, there is, however, a danger of this change swinging too far. Since task standards need only be set for the whole assembly and the subordinate parts merely balanced, it is an easy way to avoid some of the preliminary job standardization and much of the paper work in operating. If equal results were possible there could be no objection, but it is well established that group effort is neither that of the least efficient or that of the most efficient, but a mean between. In fact, the effort may be even below the mean if leadership is not properly exerted, and leadership cannot be properly exerted when groups are large. It is in this respect that group applications have been carried beyond their suitability. Such companies as the Western Electric have gone through this stage and are now deliberately returning to individual applications, except where jobs are definitely interrelated and where leadership can be effective. Plans which use the man-minute for production control have spread rapidly during the year and are undoubtedly achieving a greater unity of control than anything ever achieved with the man-hour, although the reason for this is not fundamental. It simply happens that such plans as those of Bedaux, Haynes, Parkhurst, and Dyer have worked out comprehensive systems for unified control and are not installed without control. Office work and all indirect work in the factory are just beginning to have extra-financial incentives. This is merely because such incentives have to follow job standardization, and employers are now learning to apply such standardization to the more difficult types of tasks.

At the same time, incentives are being extended to supervisors and executives, some on a profit-sharing basis, but many on a real accomplishment basis. The former is effective for the highest executives, but much less so for those below the general manager, because the relation between the reward and the effort is always remote under the profit-sharing type of plan and may even be quite unrelated. Furthermore, incentive plans are being scrutinized on their real merits and are not being accepted so readily because of high-pressure sales on the part of consultants. (C. W. Lytle, "Wage Incentive Methods.") It is not unusual in well-managed companies to have as many as 80 or even 90 per cent of the employees on an incentive basis today. Some companies are even applying incentives to the elimination of accidents. It has come to be the accepted thought that safety is primarily a management responsibility, but the fact that our industrial accidents last year amounted to $1,000,000,000 indicates the need for still better attention to this problem.

Obsolete Equipment and Its Relation to Profits

Probably the most important questions that confront the manufacturer today are the relation between the condition of productive equipment and profits, and the replacement of machinery which in point of service may have many years of usefulness, but which is incapable of satisfying the latest fancies of the consumer market or competing with more recent and improved machinery. This has been a difficult point for manufacturers, and has prompted a request for a study of this problem.

The important phases of the industrial-equipment studies are, (1) to bring out facts showing the relation of equipment obsolescence to production costs, and (2) to discover, if possible, a means for correctly evaluating and providing for obsolescence in cost accounting. The first result is expected to be obtained by the study of machinery among manufacturers of the several classes of machinery. The second result is expected from an investigation among the users of such machinery.

The practical value of such studies will be, it is hoped, the establishment of a truer accounting for obsolescence as a hazard rather than an arbitrary compromise as at present. Wear and tear, or depreciation, is a scientific problem, and can be determined with considerable accuracy. Obsolescence is more nearly analogous to fire. As a risk it cannot be predetermined any more than can the date a building will burn. An arbitrary basis of accounting for the two factors does justice to neither, and fails adequately to provide for a fund for replacing the machinery when its value has been destroyed by the factor of obsolescence.

Keen competition, as well as reasons other than inefficient machinery, has caused some of our plants to liquidate.

Plants that have had the money to invest have discarded old equipment as far as possible, but those industries which have been running and which have antiquated machinery have been dragging along at a loss or no profit, or have liquidated.

The chapter on Industry. in the report of the Committee on Recent Economic Changes, gives striking evidence of the differences in utilization of productive factors by the prosperous as compared with more backward manufacturing industries. The yardstick adopted is productivity per man-hour. In general, where productivity has increased, industry has been prosperous; where it has increased but slightly or has decreased, the industry is in difficulty.

Utilization of power, of buildings, and of equipment are important factors. The increase in the manufacturing of machinery, for example, probably approximates or perhaps reaches higher levels than the increase in industrial power.

Experience is showing that in these competitive days the mathematical relation between obsolete machinery and profits is an inverse ratio.

A few months ago, Ray M. Hudson, Assistant Director, Commerical Standards, said that:

> As competition increases, price cutting occurs, until the craze for volume swells sales expenses, increases distribution costs, and reduces profits, even though the factory be operating at capacity. In cases where factory capacity is in excess of current sales volume, pressure for greater volume becomes acute, and greater effort is made to secure it. New ideas in selling develop.
>
> Among recent proposals is "progressive obsolescence," meaning the quickening of sales by inducing people who can afford to buy a greater variety of goods on the same principle such people now buy autos, radios, and clothes, i.e., "not to wear out but to trade in or discard after a short time, when new and more attractive goods or models come out." While some stimulation of obsolescence is not uneconomic, the danger lies in its probably application to buyers who cannot afford it, and who might better put more of their income into more permanent investments. That uncontrolled obsolescence has great potentialities for economic waste and loss is obvious. Too high a frequency of purchase is relatively as wasteful for the consumer as too high a frequency in change of design, size, style, or model is for the manufacturer and the merchant.

Standardization as a Factor of Management

Mass production is dependent upon the adoption of dimensional standards. Standards of this kind—in fact, most of the standards in existence today, as distinguished from "quality specifications"—have been developed by producer organizations operating either as individual firms or as groups of firms brought together through some such agency as a trade association.

With few exceptions, industrial executives are in favor of such dimensional standards as will permit mass production, and of quality specifications for the materials purchased by them. The more progressive of the executives are in favor of service or performance specifications for goods sold by them and their competitors, although not a few of them are opposed to "composition specifications," which are looked upon by them as tending to retard improvements.

To the extent that standardization does in fact retard improvement it is disadvantageous; to the extent that it eliminates the less desirable in favor of the better commodity it is advantageous. At an ever-increasing rate industrial executives are realizing that when properly carried out standardization simultaneously eliminates the unworthy and identifies and sets forth the best, not as a finality, but as a starting point for improvement.

Reasonable specifications, formulated after thorough interchange of ideas and experiences of the manufacturer and the user, and setting forth those requirements considered essential to safeguard the consumer without hardship to the manufacturer, serve to show to both parties to the contract what service the commodity must render, and how it must be manufactured in order to fit it for use. It is to the best interest of all persons concerned that the specifications be formulated jointly by both parties to the contract, working together harmoniously, each benefiting from the knowledge and experience of the other.

Management may be defined as the judicious use of means to accomplish an end. Business management naturally consists of the careful guidance of men and material in the production and sale of a commodity that will produce the desired end—namely, dividends.

The industrial community is receiving valuable assistance in establishing means for accomplishing these results from the Bureau of Standards.

Management is vitally affected by nationally recognized grades, by standards of quality. To fully analyze this question it is always well to consider it from the standpoint of the interests of the various branches of industry.

One of the commercial standard publications quotes R. P. Lamont, Secretary of Commerce, as saying that:

> Standards constitute the common language, even the common law, of modern industry and commerce. Certain standards, such as those used for weights and measures, are essential for public convenience, health, of safety, and have been fixed by legislative enactment. Mandatory standards of this character, however, are few in number when compared with the large and steadily growing volume of standards developed by industry and commerce and voluntarily maintained.
>
> Recognized standards of this character developed by cooperative effort on the part of designers, manufacturers, distributors, and users constitute a powerful force for eliminating waste in production and distribution. Simplified practice, meaning elimination of unnecessary variety of products, and concentration on a small number of standard products, offers many striking examples of the enormous benefits to be gained through voluntary cooperation. Many different groups must cooperate not only in developing standards but in establishing and maintaining them in general use.
>
> Such voluntary cooperation is of equal value in providing means whereby standards may be modified to meet changed conditions or new development.

Continued calls for cooperation in the endeavor to establish standardization as a factor in management have caused agencies of the Government to augment its service to industry, and its Division of Trade Standards is working with nearly fifty different commodity groups in perfecting standards of grade and quality for their products.

The enlarged export business of the United States and the rapidly growing use abroad of simplification and standardization has brought a demand for further cooperation in the translation of American standards and specifications into foreign languages for the convenience of foreign consumers. Service of supply, including transportation facilities and means of communication, has advanced to the point where buyers no longer shop exclusively in the nearest market.

Russell Forbes, the nationally known expert in purchase practice, in his book entitled "Government Purchasing," says, according to the A. S. A. Bulletin, that: "The treatment of the purchasing problem will be of direct interest not only to federal, state, county, and municipal buyers, but also to every one concerned with the allotment and expenditure of tax moneys, and to purchasing agents of large industrial concerns." He recognizes with unusual clarity the importance of standards as a factor in the purchase problem, and cites important instances of savings gained through the standardization technique.

One factor which has contributed largely to the notable increase in manufacturing efficiency in the last two decades has been the development of standards in cost accounting. The old system of trial and error has been replaced by accurate facts, and many wasteful production practices have been thus discovered and eliminated. The key to the practical use of cost accounting in manufacturing has been the study of the cost of producing individual items and of performing individual operations.

Standardization has unquestionably been a definite factor in inventory and cost reduction. Its application, however, in a wide manner seems to be more confined to staple articles not involving style or temperamental selection. Its future application might possibly, with beneficial results, be directed to standardization of an article of one concern, rather than of the same article as produced by many.

The great competition today is between industries, and it is natural, therefore, if members of a given industry desire to maintain the standing of the industry as a whole and a recognized standard for their product, they should set up a minimum level for their commodity below which quality shall not be allowed to fall, in order that the public may buy with assurance and confidence, and that the commodity as a whole shall retain the goodwill and command the respect of the purchaser.

Coordination of Production and Distribution Methods

The answer to coordination in production and distribution methods is not price cutting, but reduction of waste in physical distribution, says *Distribution Economy*. In this connection, the magazine asks, "When your goods leave the production line, are they handled with the same mechanical skill that produced them?"

Efficiency and scientific management are essential factors in the successful operation of the modern industrial plant. Great progress has been made in these directions by American manufacturers during the last decade. Waste has been eliminated in a thousand different ways through improved business practice, and through simplification of processes and methods of manufacture.

Dunn's International Review, in discussing this subject editorially, says:

> With this lowering of production costs, it is now recognized that the next great field for the reduction of industrial waste is in methods of distribution. Today, the necessity for satisfactory and economical distribution as a means of passing production economies on to consumers is reinforced by the realization that, in many instances, effective distribution is the deciding factor in the new group competition between industries, commodities, and distributors. The idea of a smoother and more economical passage of merchandise from producers to consumers is growing rapidly, and it is to be hoped that the problem will permit of an early solution.

Relatively little progress has yet been made in analyzing distribution costs from the standpoint of the cost of handling individual items or performing individual services. There has been some progress made, and several agencies are attempting some work in this field. Investigations in wholesale and retail distribution for several lines of trade, with particular reference to the small as well as the larger producer and also to the several methods of distribution, show the possibilities for reducing costs through more uniform methods. The purpose of these reports is not so much to provide comparative data on operation costs or to specify wasteful practices, but rather to present a method for functional-costs allocation which may easily be adopted by any industry or branch of industry in determining the profitableness of their own individual commodities, customers, or service.

There have been several attempts in some particular lines of industry at consolidation of plants producing similar goods to bring about the coordination of production and distribution methods. Some of these mergers have been accomplished and should result in diminishing the competition in the distribution of the product.

Various chapters of the report of the Committee on Recent Economic Changes stress the striking progress in coordination of production and distribution. Progress in the later years of the decade has been particularly striking. A recent report, signed by sixteen of the most important figures in industry in the country, including President Hoover, makes this striking statement:

"In the marked balance of consumption and production, for example, the control of the economic organism is increasingly evident," and the Committee insists that "it would seem that we could go on with increased activity, but only if we develop a technique of balance."

Waste Elimination and Its Effect on Industry From a Managerial Standpoint

During the past year considerable progress has been made in reducing factory waste. Early in the year a committee was organized to encourage as an annual national program the holding of campaigns within industry to eliminate waste. During April a large number of companies held an exhibit of waste campaigns which consisted of exhibit boards of factory waste gotten by employees, as well as meetings to stimulate interest in the boards and in contributing suggestions as to how waste might be reduced. Prizes were given for the best board and for every worth-while suggestion.

The history of this movement dates back to the yearly Management Week, which, after being held several years, was discontinued last year as it was felt that the work of attracting attention to better management methods and the responsibility of management could more effectively be carried by individual organizations. On the disbanding of the Management Week Organization, attention was called to the fact that in 1926 the topic of Waste Prevention had been sponsored by the Week and that as a part of it an exhibit campaign had been arranged by Westinghouse Electric and Manufacturing Company at East Pittsburgh. This campaign has had such successful results that the Newport News Shipbuilding and Drydock Company, and later the subsidiaries of the U. S. Steel Corporation and many other plants, organized campaigns. The amazing savings and other benefits secured from the campaigns brought the demand for coordination and stimulation of the work, as a result of which the committee mentioned above was organized.

As part of the movement in 1929, besides the number of companies that put on campaigns there were elimination-of-waste meetings held in over twenty-five cities. Hundreds of booklets describing campaigns already held and how to organize them were distributed during the year to company executives, and it is planned to continue the work annually every April. The most spectacular and successful campaign was organized by the Oakland Motor Company at Pontiac, Mich. Their campaign, called a "War on Waste," opened with a sham battle by the state guards against a waste stronghold, and was followed by an extensive two-weeks' campaign. Eleven hundred employees contributed over twenty-five hundred suggestions on reduction of waste, of which a third were classed as valuable, and it was estimated by the company that half a million dollars would be the immediate saving of the campaign, with a like amount to be secured later.

The tendency to more serious thinking on the subject of waste elimination is developing a better basis for real action along this line in industry. Salvaging is only a minor part of real waste elimination. We need to give more thought to *"not wasting,"* as Mr. Ford says, than to reclaiming what is waste.

In the attainment of the elimination of waste, whether of time, material, or human energy, this fact is basic and fundamental. It affords a common cause in which all interests or elements find many opportunities for growth and for the creation of greater wealth, not alone for the few but for the many—in fact, for the Nation.

Waste elimination, by the reclamation and reuse of materials, and the development of commercially valuable by-products, has also been very striking. In the case of reclaimed rubber alone, the figures run to more than twenty millions in a single year.

Waste-elimination programs offer every one in industry an opportunity to cooperate, and are now recognized the world over as a fundamental factor of force operating to help stabilize business, to lower costs of production and distribution, and thus lower the cost of living. Beyond that it works to advance still further our standard of living to conserve our material and human resources.

Greater possibilities for coordination with other activities also obtain. In this connection, attention is again called to the tremendous wastes in distribution, estimated at eight billion dollars annually. At least three billion of this is attributable to waste in physical handling and transportation. A major portion of the other waste also occurs through lack of simplication of method and practice.

W. L. Conrad, *Chairman.*

MAN-52-2a

Twelve Years' Experience With Economic Production Quantities

By C. H. BEST,[1] INDIANAPOLIS, IND.

For twelve years economic production quantities have governed the sizes of production orders in the plant of Eli Lilly and Company, manufacturers of pharmaceutical and biological products, at Indianapolis, Ind. This paper outlines briefly some of the major results of this practice, both direct and indirect, and discusses some of the cost-accounting problems that were encountered in the derivation of the formulas. The discussion of cost-accounting problems is limited to such problems as might be generally encountered in other plants.

THE firm of Eli Lilly and Company manufactures and ships from stock approximately 2400 products which are marketed in over 8500 different packages. The problem is to maintain stocks of these 8500 different items at the lowest possible combined cost of labor of preparation and charges for carrying the merchandise until it is sold.

It was recognized long before 1917 that the quantity produced in a single batch was one of the important factors in determining the cost of producing and carrying the merchandise. Charts and curves were drawn to assist the individual whose judgment determined the batch sizes. These aids were better than nothing, but they could not even approach the solution of the problem.

In the early part of 1917 work was begun on the assembly of data from which to derive mathematical formulas that would determine the economic production quantity. The task was to express algebraically the total cost of producing a batch of merchandise and of carrying that merchandise until it was sold. This expression has been termed the "total-cost expression," and will be referred to by this term. The first derivative of the total-cost expression, when set equal to zero and solved, gives the economic production quantity or the cheapest batch size that can be made. Larger and smaller batches than the economic production quantity will both produce a higher unit cost than batches made in this exact amount.

The simplicity of the calculation for determining economic production quantities is shown by the following example: The formula used is

$$N = 262.8 \sqrt{\frac{Y}{M + 202}}$$

where N = economic production quantity in units
Y = number of units sold per year, and
M = cost of material in cents per unit.

Let Y = 14,000 gallons and M = 850 cents per gallon; then the solution of the formula gives N = 958 gallons, or the economic batch size.

The solution is an easy slide-rule calculation.

To make a larger or smaller batch will cost more than it will cost to make a batch of 958 gallons.

Late in 1917 the first departments were issued orders for production quantities that were determined mathematically.

During the year 1917 the production of the plant was handled in 25,633 batches with a labor force of 554. Since 1917 the annual output of the plant has very materially increased. In 1928 the increased output was handled in 13,453 batches with a labor force of 482.

A force of about 23 persons carries on the routine detail of the Planning Department, which department has been put into operation since 1917. The Planning Department also operates the perpetual inventory records of finished stock. The work done by the Planning Department is deemed practically indispensable, but the cost of maintaining it would be very substantially more than present costs if production quantities had not greatly reduced the number of operations that have to be planned. Whether this department could function properly at a reasonable cost without economic production quantities is a question.

Automatic materials-handling equipment has reduced trucking to an absolute minimum. This mechanical handling, as well as machine bottling, gang bottling, and machine labeling, has greatly reduced the costs of the various operations that they do. Certainly to revert to 25,000 batches per year would cause a greatly reduced volume of work that could be handled by this equipment, and consequently reduce the profit from the investment in these devices. It is quite probable that, in many cases, a sufficient return to warrant the investments in these devices could not be estimated if it were not for the reduced number and the consequent increased sizes of the runs that are now made.

During the past five years the inventory of raw materials has been reduced 21½ per cent by taking advantage of conditions that were brought about by larger and less frequent batches or runs of staple products. Larger and less frequent batches of staple products suggested scheduling the production of these items in advance, in order that raw-material purchases could be scheduled to arrive just in time to meet the production schedules. The average inventory of raw materials in 1928 was $185,000 less than it would have been at the same rate of turnover as was experienced in 1923. This $185,000 has virtually been extracted from the business as an indirect result of economic production quantities.

During the year of 1917 the finished-stock account was turned three and two-thirds times. During 1928 it was turned four and one-third times. While merely reducing the number of batches to be processed per year would have gained some of the advantages mentioned in preceding paragraphs, to gain an increase in turnover of finished stock at the same time indicates that regulation of batch quantities has followed the principle of production at minimum cost.

To sum up, economic production quantities have afforded, or have assisted in affording, the following advantages to Eli Lilly and Company:

1 Considerably more production with 13,453 batches in 1928 than with 25,633 batches in 1917.

2 Considerably more production with a labor force of 482 in 1928 than with one of 554 in 1917.

3 Planning-Department supervision of production at reasonable cost.

4 Increase in application of mechanical handling of materials.

5 A reduction of 21½ per cent in raw-material inventory.

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[1] Supervisor of Materials, Eli Lilly & Co.

Contributed by the Management Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

6 An increase in turnover of finished-stock account from three and two-thirds times per year to four and one-third times.

It would be quite impossible to designate a specific cause as being responsible for any of the six advantages listed above. A progressive management is constantly directing efforts toward the accomplishment of these six, as well as many other objectives, and it is undoubtedly true that the application of the principle of economic production quantities has contributed its share toward making these economies possible.

Some Cost-Accounting Problems

It would be very convenient if unit costs of record in the Cost Department could be used directly in the formulas for the determination of economic production quantities. But the cost plan was not designed to furnish unit costs for this particular purpose. Consequently there were numerous adjustments to be made in costs before they could be used.

The cost plan furnishes a unit cost of production for each batch of merchandise processed. This unit cost is broken down into a unit material cost and a unit processing cost. Burden is included in the latter.

The burden includes the cost of all non-productive departments, such costs in productive departments as changes in equipment between runs, and certain preliminary steps in the actual production. It increases the departmental costing rate per machine-hour or per labor-hour.

Following are some of the items of costs which are included in burden, although each item represents a practically constant cost per batch, regardless of the number of units to be produced in the batch.

1 Preparation of complete data on stock and sales to serve as notice that stocks must be replenished.

2 Blue-printing and registration of the production order.

3 Adjustments to perpetual-inventory records for raw materials to be used.

4 Weighing, checking, and verifying raw materials in the stock room.

5 Scheduling production by the Planning Department.

6 Checking or assaying the finished product.

7 Calculation of the bottling and finishing orders.

An hour of time spent on the operations listed is just as expensive as an hour of labor in a production department. These costs cannot be carried as overhead charges into an expression of unit cost if this expression is to be differentiated to determine the batch size that will give a minimum unit-production cost.

The cost data for use in the formulas for determining economic production quantities were obtained by adjusting the unit labor cost of record. Such elements of this cost of record as are shown above were introduced into the total-cost expression as a series of costs per batch. The unit labor cost of record was reduced to compensate for those component parts of this cost that had been introduced, in some other manner, into the total-cost expression. The remainder of the unit labor cost was then used as the unit cost of the actual production. In this way as much use as possible was made of the existing record of costs.

For a number of years it was not possible to determine economic production quantities for a line of items made in one large department. The items produced in this department were quite varied in nature. Some were finished in one day, while others took five weeks. The largest equipment in the department would handle 100 times the quantities that the smallest equipment would handle.

The Cost Department could not determine a set of rates that would cost all these products fairly. Several plans were tried out. Records over six or twelve months would be accumulated, then an attempt to use the costs in the formulas would prove the data to be unsuitable for use.

A very detailed study of equipment and costing rates was finally agreed upon as a possible source of a solution. This was carried out and a satisfactory cost plan resulted.

After sufficient cost data were accumulated the formulas for economic production quantities were derived. Calculations employing the new formulas showed that with less than $3500 investment in new equipment, savings could be effected that would more than justify the expenditure. The equipment was ordered promptly and installed. As a result the batch sizes of 155 items were increased.

Some of the 155 items have not yet been produced since the revision in batch sizes. However, during the first seven months of 1929 the costs in this department, including overhead charges, represent an annual saving of $11,950. The annual saving will probably reach $15,000 when the full benefit of the change in equipment is realized.

While it took a number of years to work out this problem, which was essentially a problem in accounting, the results have justified the effort.

The experience of Eli Lilly and Company with the application of the principles of economic production quantities indicates that it is just as necessary to study the cost-accounting system as it is to study the problems of the production departments. In fact the cost-accounting problems have been more difficult of solution than the production problems.

MAN-52-2b

Use of Economic Manufacturing Quantities

Obstacles Encountered in Introducing Mathematical Formulas for Economic Manufacturing Quantities—Lot Sizes

By ROBERT W. KENT,[1] BOSTON, MASS.

For the sake of establishing better manufacturing procedure, the author points out methods for determining how much to manufacture of a particular item or part at one time or in one lot. He discusses what is meant by economic manufacturing quantities, the aid toward increasing profits that comes from use of proper formulas, and states that minimum economic manufacturing cost can be obtained only through application of the principles made use of in developing a proper formula to fit each specific case.

IT IS the purpose of this paper to encourage the use of scientific and mathematical development in effecting manufacturing economies through effectively determining "how much" to manufacture, of a given item or part, at one time or in one lot.

Formulas are available that will prove valuable if used. It is true that attempts to understand them may prove discouraging unless one is either very patient or of rather above-average mathematical cleverness. Successful and practical manufacturing executives do not, in the author's experience, usually develop the nimbleness in transposing concrete facts and experience into abstract formulas that is necessary to rapidly digest and "become sold on" the practicability of using a lot of x's, y's, and k's to tell them how much should be manufactured at one time. Neither are they usually very deeply impressed by a lot of modernistic appearing curves or plots or by tabulations of untold quantities of figures.

A successful manufacturer is usually very apt to justly fear anything that savors of mystery or magic in any form. Furthermore, anything not readily subject to proof or anything involving complications of any kind is apt to hide errors, and factory procedure, to be successful, needs to be as foolproof as possible. Obscurity of any kind reduces fool-proofness. Since the average manufacturing executive does not appear to have sufficient mathematical mental agility to clearly, thoroughly, and readily grasp the development of formulas for mathematical determination of economic production lots or manufacturing quantities, he should prepare himself to settle down and really seriously and patiently set about understanding how the particular formula recommended for his use was derived. It may be that he must accept some of the mathematics on faith, but he at least should have explained to him the factors used and why, and he should substantiate them.

Circumstances alter cases, and no one formula can be used universally. In this paper it is the endeavor to point out that, for the sake of establishing better manufacturing procedure, management will do well to take whatever time is necessary to assure itself that it fully comprehends, first, what is meant by economic manufacturing quantities, and, second, that using a formula that fits the individual case will aid in increasing profits, and, third, that minimum economic manufacturing cost can be obtained only through application of the principles made use of in developing a proper formula to fit a specific case.

The following is a summary of experience with the adoption of economic manufacturing quantities:

Making effective use of scientifically determined economic manufacturing quantities in the normal manufacturing establishment becomes the function of those delegated with the work of planning production or operating a production-control department, but is nevertheless the responsibility of management, as it is probably the only available method of knowing definitely that minimum consistent manufacturing costs are being maintained and that inventories are so controlled that minimum practical investment is tied up in them.

During the last fifteen years the author has spent a large portion of his time in work which involved the development or improvement of production-control methods, together with the introduction of such methods and making them operate. Production-control methods, as developed and installed by large numbers of industrial engineers, have ranged in their intricacy from the point at which they were entirely too cumbersome to meet the requirements of sufficiently economical operation to the point of simplicity to the extent of neglecting many known applications of science which probably were essential to making any production-control procedure sufficiently valuable to warrant its use.

Planning and controlling production is simply an element in the application of scientific management to industry. The development of scientific management itself has, without question, been seriously hindered by the fact that perfectly good, sound ideas of high-grade technicians have been offered to industry which, in general, was in so youthful a stage of development as to be entirely unable to understand, appreciate, or make use of perfectly sound but nevertheless advanced technique.

The author many years ago reached the conclusion that, in introducing scientific management methods, one of the prime requisites of success consisted of so regulating the dose to be given that all of the medicine would be effectively and completely absorbed. In other words, it appears essential that those who have delegated themselves to the job of introducing the application of science to industry must prepare themselves to be satisfied with accomplishment which falls far short of the goal which they are able to visualize as a result of their manipulation of basic scientific principles, mathematics, and the work of the technician in general.

It is believed that some of our most learned and accomplished disciples of scientific management have fallen far short in their accomplishment of results by not being willing to be satisfied with a 30 per cent accomplishment of the goal rather than 100 per cent accomplishment. Had these same capable and experienced technicians actually tried to accomplish only one-third of what they were able to visualize as being possible, then their service to mankind would have been greater than it has, from the fact that the 30 per cent accomplishment would have actually been realized.

For instance, in the application of scientific management grievous errors frequently have been made through applying

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Contributed by the Management Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

methods for the control of direct labor costs which involved increased indirect labor costs (clerical effort) to absurd degrees. Examples have arisen where the present-day work of the industrial engineer has been to undo the work of predecessor engineers, through simplifying clerical detail, in order that advantages gained might not be outweighed entirely through the burdensome indirect cost of carrying out the prescribed methods.

Just as errors have been made in applying methods involving excessive amounts of "red tape," frequently one meets with situations where excessive amounts of mechanical handling equipment have been applied, and, in considering the use of mathematical formulas for the determination of economic manufacturing quantities, danger exists in including in the formula certain factors which have no particular bearing on the specific case. For instance, a space factor, or space charge, is frequently included in a formula for economic manufacturing quantities, and applied even in cases where the particular factory under consideration is entirely overequipped with floor space. In fact, it is probable that the majority of manufacturing plants in operation today have floor space available perhaps 50 per cent in excess of their real requirements. Obviously, it is not basically sound to assume that inventory is accumulating a rental charge under such conditions.

The foregoing emphasizes the thought that the particular conditions encountered in any manufacturing situation must be carefully weighed and balanced against the particular mathematics and technique being applied.

All of this discussion may appear to be somewhat far from the subject of establishing economic manufacturing quantities. However, the author in the course of his experience has had several occasions arise where the use of mathematical formulas for the determination of proper quantities which should be manufactured at one time seemed desirable and essential, and he has, with varying degrees of success, actually made use of such formulas. Installations of methods involving the use of such formulas have proved reasonably successful in connection with the manufacture of hosiery and underwear, paper boxes, chairs, office furniture and equipment, and in connection with the manufacture of parts for office calculating equipment, electrical instruments, and many similar products.

The early reaction, in the author's experience, to the attempted use of scientifically determined economic manufacturing quantities was that, were the quantities mathematically established as the proper ones to manufacture at one time actually made use of, inventories increased to an extent which sound business judgment proved was dangerous. Hence, instances are known where economic quantities were carefully calculated and then arbitrarily quartered or halved in order that inventories might be kept within reason. It is probable that the reason for the necessity of thus reducing the quantities which mathematics had told should be used, lay in the many intangible things which it is so hard to anticipate, such as obsolescence due to sudden style changes, or obsolescence due to the development of new materials (as, for instance, the introduction of rayon into the textile industry as a whole).

It is possible also that in the past there has not been sufficiently appreciated the extent to which return on capital invested in industry should exceed the return on investment in sound negotiable securities. It is very common for members of the producing phases of industry to think more or less of 6 per cent as a definite interest rate to be used in all calculations that they make, whereas it is probable that return on investment in inventories, equipment, etc., used in industry might much more properly be figured at from 9 to 18 per cent, in order that investors in industry may be assured of an added income to warrant their taking the added risk of business over banking. It developed, for instance, that a very real cause of the necessity for halving or quartering manufacturing quantities as calculated through the use of formulas, in the author's early experience with them, was that too low an interest rate on investment and in inventory had been used. The modern economist, as well as the investment banker, in analyzing and diagnosing business situations, more or less accepts as standard the necessity for earning returns in excess of the 9 per cent referred to. The risks brought out through the possibility of changes and fluctations in material prices, obsolescence due to new developments, credit stringencies, or business depressions of any kind, require that planned returns should frequently be double normal attainable returns on negotiable securities. Is it not clear, then, that it is a fallacy to use such a figure as a 6 per cent interest rate in determining cost of carrying inventories? Even when the higher interest rates referred to are made use of in attempting to program operations, unforecasted happenings almost always reduce the return from that planned. It is believed that it is safe to accept as an axiom that business return on investment should be no less than one and one-half to three times the safe return to be realized on sound, marketable securities.

As we know, the preparation cost, or the cost of making ready the various necessary equipment to run a production order of a given quantity, preparing the necessary forms, handling order through the plant, etc., is one of the most influencing factors in mathematical determination of an economic manufacturing quantity. The fact that in many industries a large portion of this preparatory work is performed by foremen, subforemen or job bosses, elevator operators, clerks, office executives, and stores or warehouse clerks, who are generally accepted as an overhead expense, interferes with proper determination of full preparatory cost, and is also one of the difficulties encountered.

In making use of mathematical formulas for determining economic manufacturing quantities it is therefore essential that in many cases entire accounting methods be changed in order that total preparatory expense may be determined. To the technician the changing of age-old accounting methods to improved methods very rarely constitutes an insurmountable obstacle, especially once he is convinced that the old-time methods are inaccurate or improper. However, to the business executive the mere thought or suggestion of changing such methods may immediately result in a decision to waive all attempts at application of scientific management in this particular regard.

Without question, a large portion of expense which finds its way into general factory overhead or, perhaps more accurately, into factory indirect labor, is, it is believed, in the majority of our plants today, made up of items which might in very many cases be quite legitimately charged to preparing cost or cost of making ready to run production orders or lots.

Attempts to segregate properly these costs from actual indirect cost, which will result in continuous analysis of the time of these many-times-privileged individuals, may result in resistance to the methods being installed to an extent that is unpolitic. In more simple terms, much of the work which goes to make up the job of foremanship as it is now constituted consists very largely of make-ready effort and is in reality direct labor cost.

It is possible that enumeration of some of the impediments encountered in actual attempts to make use of formulas for determination of economic manufacturing quantities may be worthy of mention in that, in being prepared for an obstacle, the obstacle may be surmounted the more easily.

In attempting to establish bases for determining size of manufacturing quantities which may have been in use in the past in plants, it has almost always been surprising to find the lack of any real reasoning employed. Lots of 1000 units very fre-

quently will be found to have been used for manufacturing quantities, for no specific reason whatever. Quantities which will keep factory workers busily employed for one day's time, or one pay period's time, frequently seem to be in vogue. Quantities which will constitute a truckload or a trayload also seem to prevail as standards employed in determining size of manufacturing lots.

All of these, of course, seem ridiculous in that they present no consideration of the real cost involved nor the effect on cost of difference in the size of lots. Yet even with these crude methods of establishing manufacturing quantities, business has been performed in a profitable manner, with the result that extreme reluctance is encountered when suggesting any changes from the established procedure. Also, considerable work has been done in connection with the establishment of financial ratios (ratios of various balance sheet items) which attempt to dictate how large inventories in general should be. Considerable data are available, and business executives talk learnedly of what should be the rate of turnover of inventories. When manufacturing quantities are established, there also are established average inventory values for the particular items concerned, and the resultant effect of establishing scientific manufacturing quantities for all the items in the various lines of product is immediately seen on the inventory in total.

If one increases the size of manufacturing lots, naturally the inventories are increased to a degree that may be considered very dangerous indeed. Also, one complicates the clerical work involved in properly tracing or routing an order through a plant if the quantities become so large as to be impractically handled in single transportation units. If, on the other hand, one decreases the size of lots, there are immediately imposed more diligent planning and layout and set-up work on the foreman and his assistants, and here again is a change from past routine which naturally arouses antagonism.

Difficulties also are encountered in selecting the proper formula to fit the particular case at hand. Determination must be made as to whether one uses as factors in the formula the direct cost only or the total cost, with or without overhead, and whether these factors include items which are really independent of quantity. Also, consideration must be given to the factors involving cost of capital. Shall inventories only be included or shall work in process be included? Must operating space charges be included as factors, and must space charges for inventories be included? Consideration must be given to all of the foregoing and the situation be weighed and the proper solution arrived at fitting the particular case in hand. Changes in rate of demand, due to seasonal trends, also frequently make it necessary to re-calculate manufacturing quantities for different periods.

Experience has proved that, if sufficiently careful consideration is given to the particular application of the formula involved, very surprising economy may be effected, and occasions have arisen where entire factory management policies were advantageously changed as a result of making use of economic manufacturing quantities. It has been the purpose of this presentation of ideas to expound the theory that it is wise to be just as scientific as conditions and personnel encountered will permit. In other words, if one simplifies the procedure of arriving at economic manufacturing quantities sufficiently to insure acceptance of the practice, one may be more definitely assured of real accomplishment than if insisting on a more dogmatic application of mathematical data. The experience with which this paper treats may be summed up somewhat as follows: No sound rule-of-thumb procedure for determining how much to manufacture at one time has been encountered in a careful consideration of nearly one thousand manufacturing establishments. A sizable field for the effecting of economies through the application of a scientific procedure of determining how much to manufacture at one time very definitely exists. It is worth while to inject mathematics into this general problem even if some elements or factors which should be included are dispensed with to make the procedure more salable. Even in instances where such formulas, even lacking certain necessary elements, are used, advantages are gained in that various items going to make up inventories as a whole are brought relatively more nearly in balance. One very distinct advantage of making use of economic manufacturing quantities is that periods of peak production and sales are met much more easily, and the additional cost, due to changing sizes of manufacturing lots, can be definitely known. It is almost always true that in making use of economic manufacturing quantities cost-collection methods are radically improved. Overhead items are brought more definitely within control, and many advantages are thus gained which were not necessarily the objects in view when the methods were adopted.

An attempt has been made in the presentation of this paper to get away from an academic or scholastic presentation, in the hope that the virtue which so surely exists in the use of formulas for determination of manufacturing economic quantities may be more widely realized and use be made of them.

MAN-52-2c

Advantages Derived From the Simplification of the Fundamental Formulas for Economic Production Quantities

By FAIRFIELD E. RAYMOND,[1] CAMBRIDGE, MASS.

The paper seeks to demonstrate that a rapid and reliable method can be developed for application to the problems most frequently encountered in planning production schedules and controlling inventories. This method is stated to be more simple than the fundamental formula developed in the author's former paper on "Economic Production Quantities." Other advantages are gained from the simplified method.

IN PREPARING the paper[2] on "Economic Production Quantities" presented to the Society by the author in 1927, it was fully appreciated that the fundamental formula therein developed would be too complicated for direct application to the practical problems most commonly encountered in planning production schedules and controlling inventories. It was pointed out at that time, both in the paper itself and later during the discussion, that only after a thoroughgoing investigation of the basic factors entering into the determination of an economic production quantity could a suitable means for selecting simplified forms be evolved. In the light of recent developments it seems that the fundamental relationship has been sufficiently well established to warrant, at the present time, a study of this problem with particular regard to a simplification of the general form. Therefore, it will be the purpose of this paper to demonstrate that a rapid and reliable method can be developed, and that definite limits exist for governing the use of each form. Besides the advantages gained from a simplification of the method of determining an economic production quantity by means of which much of the implied calculations can be dispensed with, others of even greater importance can be attained.

First, a wide range in the size of any manufacturing lot can be established from the limits governing the simplified form which can be used to adjust production schedules, to account for fluctuations in the sales demand, and to offset errors arising from estimates or sales forecasts or from uncontrollable circumstances in the manufacturing operations.

Second, conservation of capital can be achieved by the production of a quantity much smaller than the apparent economic quantity, if the increase in cost due to the smaller lot size does not impair the normal profit expected in return from the sale of the article. In determining the permissible variation in production quantities it was found that considerable latitude can be obtained for a very slight increase in the minimum ultimate unit cost of any unit of production. If the production quantity calculated from a simplified form, which in all cases is greater than the economic quantity, is permissible for this reason, a quantity smaller than the economic quantity which does not exceed these same permissible limits can be used instead to better advantage, as the amount of working capital required for production in this case will be much less. Much criticism of the economic quantity method of production control has developed from the fact that an increased amount of capital was required to achieve the desired reduction in cost due to the ability to select accurately the economic lot size which in the end entirely offset the apparent gain to be thus derived. Now by the greater knowledge that is available as to the effect of the lot size upon the ultimate unit cost, a production quantity can be determined which should satisfy all situations.

Third, the savings which can be made as a result of improvements in design or the method of manufacture or by more accurate methods of production control can be determined for any case. An index of the change in cost for any two conditions of the same unit of production has been developed which may be used to compare one with another, without necessitating the actual determination of the various total cost items involved. This should be of considerable advantage to the process engineers and those responsible for the continuous improvement of manufacturing operations in general. All of these advantages can be realized by various methods of applying the chart accompanying the calculation sheets. The procedure for each case is fully described in the latter part of the paper.

Calculation Sheets—Selection of Simplified Forms

Before attempting to establish these principles supporting the proposed method of selection and limits of variation, attention will be called to the calculation sheets (given in Tables 1 and 2) which embody the results of this study. These sheets were prepared for use directly in any planning or production control department without requiring a particular knowledge of mathematics or a specialized engineering training, and have been divided into two parts, one of which is optional. The first, for general use, outlines the procedure for determining the simplified form applicable to any specific problem. The second provides means for establishing the maximum allowable limits of variation in production quantities from the ideal or economic quantity, for any problem, with due regard for the normal profit expected in return for the sale of such articles, and provides a check as well upon the method of selection in Part I (Table 2) by the determination of the permissible variation in the answer for a given form.

It should be noted that the last section can be omitted when the probable limits of usefulness for a given case have been previously determined or assumed from experience to warrant the use of the form selected without further computations. In fact, the limits obtained in the second part, when once calculated, will be applicable as long as there is no radical change in the product or process, and will have to be recalculated only when a new form is selected, should the form index show that the arbitrary limits used in the first are no longer reliable.

The proposed method has been so arranged that the minimum amount of figuring is required; in fact, the major part of the

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[2] See Trans. A.S.M.E., Management Division, January-April, 1928, vol. 50, no. 10, p. 65.

Contributed by the Management Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers.

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work in the first section, which is most commonly used, may be accomplished by a rapid inspection of certain index ratios, the values of which may be calculated with sufficient accuracy through the use of a slide rule. Moreover, only two significant figures need be used in the value of any item to yield entirely satisfactory results. Again, if a new form has to be selected

TABLE 1 INTERPRETATION OF DATA

Item	Definitions	Symbols
1	*Unit Material Cost* (in dollars per piece). (This is the total unit cost of the material used in making the part taken at the time it enters the process or is set down at the first operation.)	m
2	*Unit Production Cost* (in dollars per piece). (Add to item 1 all labor and overhead charges incurred in fabricating or assembly operations on the piece, except charges arising from the set-up and dismantling of the machines which perform these operations, and charges for production control entered under item 3, as well as such charges appearing in item 8; both of which should be removed from overhead, distributed upon operating time, if used.)	c'
3	*Preparation Cost* (in dollars per lot). (This item includes total labor and overhead charges involved in setting up the machines for fabrication of the parts or the assembly line, and dismantling the set-ups after parts are produced, as well as the cost of writing and issuing the production order, production control costs, or any charges directly pertaining to the "lot" and not dependent upon the quantity produced in the lot.)	F
4	*Unit Production Time* (*a decimal figure in days*)[1]. (Determine for each operation the time consumed to perform the operation for one piece. If this is determined on an hourly basis it should be divided by the average hours per working day in the week. If the production rate in pieces per day is known, the reciprocal of the production rate per day for each operation. Add the resulting decimal figures together to obtain the unit production time for all operations.)	t
5	*Consumption Rate* (pieces per year)[2]. (Obtain the most reliable estimate possible for the total consumption of this part or assembly, whichever the case may be, for the current year.)	Y_a
6	*Interest Rate* (in per cent per year)[2]. (Obtain the figure for the interest rate in per cent per year which ordinarily would be paid on borrowed capital and which would be used to compute the cost of capital employed.)	i
7	*Space Charge* (dollars per sq. ft. per year)[2]. (Add together all charges resulting from taxes, insurance, maintenance, depreciation, interest, etc., for the building, equipment and fixtures, heat, light, etc., accruing during the year to the finished stores section, and divide the total for the year by the total floor area for all spaces covered by these charges.)	v
8	*Average Height* to which storage is permitted in finished parts stores (in feet). (This height should be measured from the floor to the top of the highest bin, which in all probability will be constant for a given stores space, or if no bins are provided this will be the height to which finished parts may be conveniently stacked one upon another, or one container upon another.)	h
9	*Unit Storage Space Required* (cu. ft. per piece). (This should represent the overall space required per article with due allowance for clearances, voids in stacking, handling space, etc. A representative figure may be obtained by measuring the space occupied by a number of these articles as they lie in storage and then reducing it to a unit value.)	B
	(Optional Data, for Use Only in Special Cases)	
10	*Rate of Delivery to Stores* (pieces per year)[2]. (When the manufacturing and sales periods overlap, determine the number of articles per day which can be removed from the process as fast as the fabrication or assembly of each is completed. If no overlap occurs the factor $k_p = 0$ should be used.)	D
11	*Number of Batches per Lot*. (When a lot is divided into batches for ease in processing. n should represent the number of subdivisions, and if the lot can be processed continuously, $n = 1/0$ or $kp = 1$.)	n

[1] If the value for the consumption rate (S) is not to be expressed in pieces per day when inserted in any one of the formulas, but as pieces per week, or per month, or per year, the value for t in days should be divided by the number of working days per week, per month, or per year, as the case may be.

[2] If it is the practice in any company to express the rate of consumption in terms other than pieces per year such as pieces per month, week, or day, the values as specified in items 5, 6, 7, and 10 should be divided by the number of months, weeks, or days normally worked in a year, overtime omitted, as the case may be.

as a result of a marked change in the sales demand Y_a, only the ratio R_w will have to be recalculated. However, if it was brought about through a change in the process, both the ratios R_v and R_w will have to be recalculated because the unit production cost c' will naturally be altered and one or more of the terms D, t, and k_p will have new values. For ordinary corrections in the labor or burden distribution rates no new form or alteration in the production quantities will be needed, but if

TABLE 2

Part I Form for the Selection of Simplified Expressions for the Economic Production Quantity or the Minimum Cost Quantity

Procedure (obtain data from Table 1)	This space is to be used for computations
Item 1 Divide v by i and multiply by $2/h$	$= \frac{\cdots}{\cdots} \times \frac{2}{\cdots} = \cdots$
Item 1 is a constant for all problems in a given plant and need be calculated but once	
Item 2 Divide B by c'	$= \frac{\cdots}{\cdots} = \cdots$
Item 3 Multiply item 1 by item 2	$= \cdots \times \cdots = \cdots = \cdots = R_v$
Item 4 Subtract k_p/D from $(1/Y_a)$	$= \frac{1}{\cdots} - \frac{\cdots}{\cdots} = \cdots$
where $k_p = 0$ for non-continuous production; $k_p = 1$ for semi-continuous production; $k_p = (1 - 1/n)$ for batch production	
(See text pages for references, and see note 1 below.)	
Item 5 Divide t by item 4	$= \frac{\cdots}{\cdots} = \cdots$
Item 6 Divide m by c' and add one	$= \frac{\cdots}{\cdots} + 1 = \cdots$
Item 7 Multiply item 5 by item 6	$= \cdots \times \cdots \quad \cdots = \cdots = R_w$
Item 8 (A constant for all problems)	$1.0 = R_s$
Item 9 Add item 3, item 7, and item 8	$= \cdots + \cdots + 1 = \cdots = R_c$

Item 10 (*a*) Select, by inspection, any one (or two if necessary) of the index ratios (items 3, 7, or 8) so that the total value of those selected will be at least $^2/_3$ the value of the index ratio R_c (item 9).
(*b*) Check off here the index ratios selected $R_v(\ )$, $R_w(\ )$, $R_s(\ )$.

Item 11 *The Simplified Form*
Place in the denominator of the simplified form the following expressions according to the index ratios checked above

If R_v is chosen, use $\frac{v \cdot B}{h} \cdot \left[1 - \frac{Y_a}{D}\left(1 - \frac{1}{n}\right)\right]$

If R_w is chosen, use $\left(\frac{m + c'}{2}\right) \cdot Y_a \cdot t \cdot i$

If R_s is chosen, use $\frac{c' \cdot i}{2}\left[1 - \frac{Y_a}{D}\left(1 - \frac{1}{n}\right)\right]$

So that the economic production quantity $= \sqrt{\frac{F \cdot Y_a}{(?) + (?) + (?)}}$

where F = the total preparation charges in dollars.

[1] If item 4 $\times$ Y_a = 0.9 or greater, omit the parenthesis $1 - \frac{Y_a}{D}\left(1 - \frac{1}{n}\right)$ from any element where it may appear.

TABLE 3

Part II (Optional) Form for Determining the Value of the Problem Index and the Allowable Variation for Simplified Expressions (Using values for items given in Part I and data from Table 4)

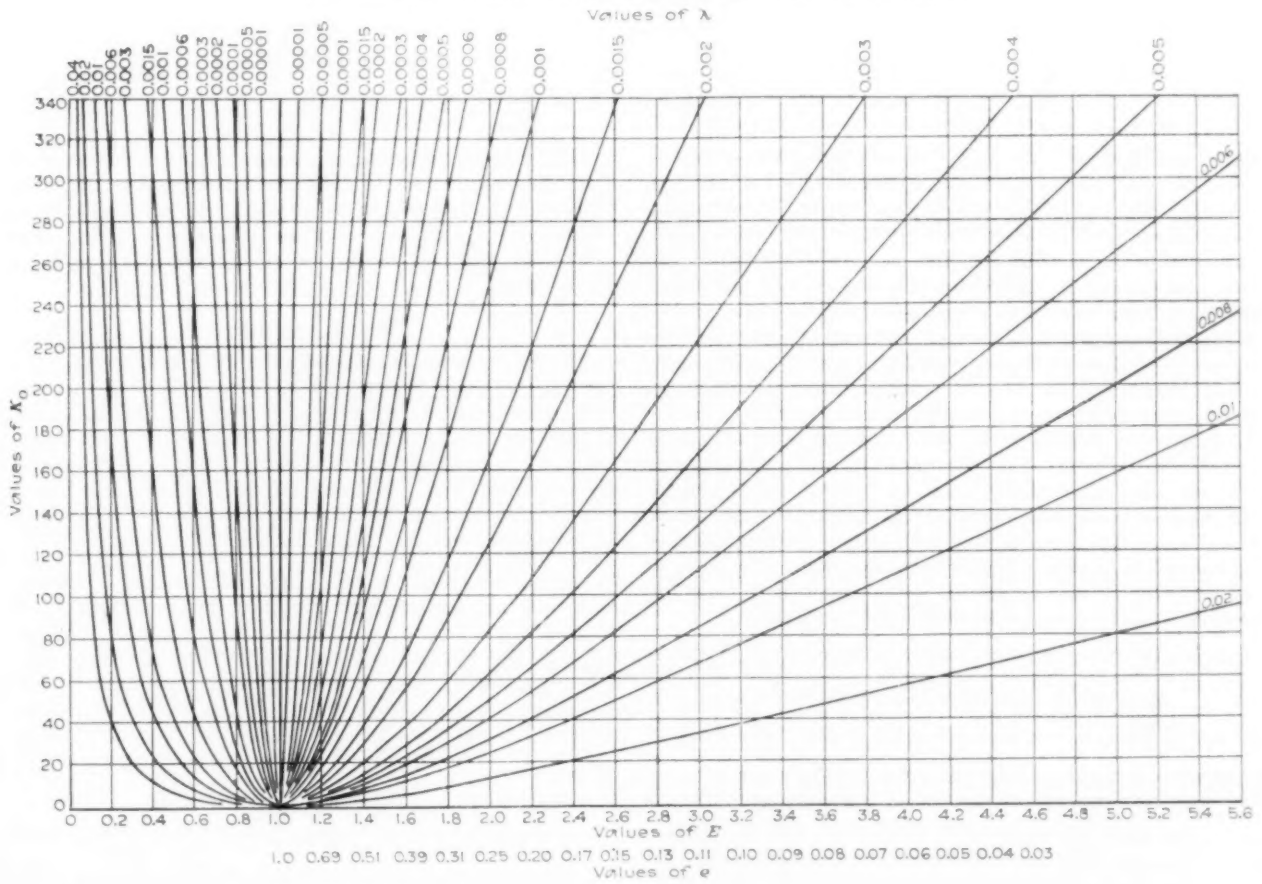
Procedure	This space to be used for computations
Item 12 Divide item 7 by item 9	$= \frac{\cdots}{\cdots} = \cdots$
Item 13 Divide c' by F	$= \frac{\cdots}{\cdots} = \cdots$
Item 14 Multiply item 12 by item 13	$= \cdots \times \cdots = \cdots$
Item 15 Multiply i by t by item 6 by 2	$= \cdots \times \cdots \times \cdots \times 2 = \cdots$
Item 16 Divide item 14 by item 15	$= \frac{\cdots}{\cdots} = \cdots$
Item 17 Find square root of item 16	$= \sqrt{\cdots} = \cdots$
Item 18 Add one to item 17	$= 1 + \cdots = \cdots = K_o$
Item 19 (Refer to the figure in Table 4) Select curve in right-hand portion of chart for an allowable per cent increase λ_d in unit cost over the minimum cost and locate point on bottom scale below point of intersection of the appropriate curve for λ_d with the horizontal line drawn through the value of K_o (item 18) on the vertical scale. Read off the decimal figure for this point, which will be the value for the form index. The value obtained from item 19 may be used in place of the ratio $^2/_3$ employed in item 10 (Part I) for selecting the appropriate simplified expression, if greater accuracy is desired, or	$= \cdots = c$
Item 20 Multiply item 9 by item 19	$= \cdots \times \cdots = \cdots = R$
Item 21 Then, turning to Part I, select the index ratio (or any group of two) which has a value greater than that for R given in item 20 and check these off in the appropriate spaces provided in section *b* of item 10. The appropriate simplified form will be obtained as usual from item 11.	
Item 22 Referring again to Table 4, read off the values of the maximum limit of variation in production quantities.	$= \cdots = E_m$
the minimum limit of variation in production quantities which lie directly below the points of intersection of the curves representing λ_d to the right and left, respectively, with the horizontal line through K_o = (item 18).	$= \cdots = E_m$

the correction is of considerable magnitude the ratio R_e may be recalculated to test the effect of such a change. The application of the calculation sheets to a specific problem has been illustrated by an example, worked out in detail, at the end of this paper.

Advantages Accruing From the Use of the Calculation Sheets

At first glance, it may seem that an undue amount of effort is required to simplify the original complex expression, in addition to the work of solving for the production quantity. However, it must be remembered that only the first section of the calculation sheets is required for the selection of the simplified form, and that the remaining sections provide valuable information which could be obtained in no other way. In fact, the practical limits of variation allowable in the arrangement and control of production schedules thus established, in all probability, will preclude the necessity of having to recalculate the economic quantity or minimum-stock requirements to account for ordinary fluctuations in business until some decided change in the situation has occurred. Accordingly, is it not wiser to make these additional computations once for all, if other computations, periodically made, can be eliminated and thereby permit a simplification of departmental routine as well?

TABLE 4 CHART FOR DETERMINING THE ALLOWABLE VARIATION e IN THE DATA, THE LIMITS OF THE ECONOMIC RANGE E_M AND E_M FOR PRODUCTION QUANTITIES, AND THE SAVINGS ACCRUING FROM IMPROVED METHODS OF PRODUCTION CONTROL AND THE CONSERVATION OF CAPITAL



Method of Simplification

If this be true, much can be gained by demonstrating that a sound mathematical basis underlies the proposed methods, because when this is once established, further recourse to the theory will not be necessary, as the procedure thus developed will automatically produce the desired results by indicating directly the appropriate form for use in any case. Briefly, it may be stated that the simplification of the general form was achieved, first by justifying the choice of that type of solution for the economic production quantity which could be most easily simplified; second, by eliminating those factors which apply only in extraordinary cases; third, by providing means for selecting for use in the desired simplified expression only those elements contained in the general expression which have a distinct bearing upon a specific problem; fourth, by indicating where constant values may be introduced for terms having a general significance and how the remaining terms may be grouped so as to shorten the labor of calculation; fifth, by determining the allowable variation in the data consistent with the permissible variation in the answer for any particular form used; and sixth, by establishing a maximum limit for the permissible variation in the answer, depending upon the conditions surrounding a given problem and the loss incurred by the use of production quantities varying to some degree from the ideal or economic quantity. The remainder of this paper will be devoted to a detailed discusion of these factors, and no attempt will be made here to discuss further the derivation of the fundamental formula, as it is assumed that its general form would not be seriously changed by additional discussion or a more extended analysis.

Approximate Solution

It should be remembered, to begin with, that the economic production quantity can be solved for mathematically in two ways, one exact and one approximate. Upon reference to the introduction of the original paper, where the two types of solution have been illustrated, it will be immediately evident that the form yielding an exact solution is much too complicated in its structure to lend itself readily to simplification, especially when compared with the simpler form for the approximate solution. The use of the exact solution brings to mind an extended controversy which has long been extant among accountants, over the use of interest as an item of cost, because in this case where the ultimate unit cost is employed as the value of articles in stock for inventory purposes, the cost of capital, based upon the current interest rate is introduced into this value. As a result an investment charge accrues not only from the capital employed in inventories but also from the cost of this capital. Compounding these costs in this manner is not recognized by accountants at the present time as representative of the true financial situation, and they prefer to post the cost of such capital to the general cost of doing business rather than inflate inventories with a charge which they believe to be of a corporate nature. On the other hand the accounting method underlying the approximate solution conforms directly with current practice and this reason alone is sufficient to justify the use of this method of determining an economic production quantity. Moreover, it was pointed out that the error resulting from the use of the approximate form would be negligible in all cases except where the production quantities were small in proportion to the fixed or preparation charges they may have to bear,[3] and that the time and labor of calculation saved by its use will far outweigh the slight increase in accuracy obtained from the use of the exact form, as the advantages gained from the more complicated expression are entirely of a hypothetical nature. Therefore, as the first step toward simplification the expression for the approximate solution will be adopted, in which case[4]

$$Q_e = \sqrt{\frac{F \cdot Y_a}{c' \cdot i \cdot \left[\frac{1}{2} - \frac{Y_a}{D} \cdot \left(\frac{1 - 1/n}{2}\right)\right] + \left(\frac{m + c'}{2}\right) \cdot i \cdot Y_a \cdot t + \frac{v \cdot B \cdot}{h}\left[1 - \frac{Y_a}{D} \cdot \left(1 - \frac{1}{n}\right)\right]}} \quad \ldots\ldots [2]$$

This is the form published in the Management Handbook Data No. 102, revised to meet the new interpretation of the production rate, referred to in footnote 4. In fact, if a case arises wherein any of these factors must be considered, it will in all probability, require the use of the unsimplified expression, Equation [1].

Major Elements

The third step toward simplification will consist in a study of the general form of Equation [2] in order to determine the relative importance of the various major elements in its composition, and to eliminate such elements as have little or no effect upon the final results when the conditions governing a specific problem are fully understood. To facilitate the discussion and provide a suitable basis for comparison, Equation [2] will be rewritten so as to show only the major elements, as follows:

$$Q_e = \sqrt{\frac{K_F}{K'_s + K'_w + K'_v}} \quad \ldots\ldots [3]$$

$$Q_e = \sqrt{\frac{F \cdot \{2\Theta Y_a - \Delta \cdot [\Theta Y_a + Y'_r (f - 1) \cdot i]\}}{c'i \cdot \left[(k + f - 1) \cdot \Delta - \Theta \frac{Y_a}{D}\left(\frac{1 - 1/n}{2}\right)\right] + \left(\frac{m + c'}{2}\right) \cdot i \cdot \Theta \cdot Y_a \cdot t + \frac{vB\Delta}{h} \cdot \left[1 - \frac{Y_a}{D}\left(1 - \frac{1}{n}\right)\right]}} \quad \ldots\ldots [1]$$

where Q_e = the economic production quantity (pieces)
f = reserve stock factor (see original paper)
Δ = coefficient of deterioration (see original paper)
Θ = coefficient of obsolescence (see original paper)
Y'_r = the total sales up to the order point in the previous sales turnover period (pieces)

All other terms in the equation have been fully described in Table 1.

Elimination of Extraordinary Factors

As the second step toward simplification, it will be assumed under ordinary conditions of business, first, that the rate of consumption or sales will remain approximately uniform for any given period; second, that the finished product will be sufficiently stable to permit a total disregard of the factors of obsolescence θ and deterioration Δ;[5] third, that for the reasons stated in the original paper, the reserve stock coefficient f has no practical value and can be omitted. As a result of the first assumption Y_a will become a constant, there being no need for any consideration of variable demand, and the stock coefficient k may be given the value of $^1/_2$. Similarly, when the factor f is unity, the term Y'_r will drop out. Accordingly a new formula can be written, where

where
K_F = all items in the numerator = $F \cdot Y_a$
K'_s = investment charge element for articles in stores $= c' \cdot i \cdot \left[\frac{1}{2} - \frac{Y_a}{D}\frac{(1 - 1/n)}{2}\right]$
K'_w = investment charge element for work in process $= \left(\frac{m + c'}{2}\right) \cdot i \cdot Y_a \cdot t$
K'_v = space charge element for articles in stores $= \frac{v \cdot B \cdot}{h}\left[1 - \frac{Y_a}{D}\left(1 - \frac{1}{n}\right)\right]$

Likewise, the typical form for all the various simplified expressions, obtainable through the application of the method outlined in Part I of the calculation sheets, can be written in a similar

[3] The practical limits of use for the approximate solution are excellently discussed in an article by Gordon Pennington, published in *Manufacturing Industries*, March, 1927.

[4] Owing to a change in the interpretation of the production rate from that used in original paper, the symbol P has been removed and the symbols D and t have been inserted in place of it. This change necessitates removing P from the numerator and dispenses with the need for the factor a' in the work in process element. To clarify this element further the terms $(m + c')/2$ have been used in place of $c'k_p$ and the repetition of the term i has been corrected, as it should appear but once in either of the first two elements. Moreover, the term h has been introduced in the third element to remove any uncertainty in the determination of the values for v and B when the space B occupied by any article in stores is expressed in equivalent square feet rather than in cubic feet as normally.

[5] When the factors Δ and θ are to be disregarded, the value of unity should be assigned to each.

manner, as illustrated in Table 5, Part I. Thus the necessity for writing out such expressions in full each time they are referred to can be avoided, and then, when one of these forms is selected for a given problem, it will be a simple matter to substitute the exact expressions, as given, for the particular elements contained therein. Another device may be introduced at this point to assist in designating in a given case, the form required for calculating a value for the production quantity Q by attaching a characteristic subscript to the general symbol (as, for instance, Q_u equals any uneconomic production quantity varying to some degree from the economic production quantity Q_e). Similarly, Q_{sv} would indicate that this quantity is determined by the use of the storage and space charge elements in the denominator. It should be noted that the numerator in all the simplified expressions is the same and is represented by the element K_F.

TABLE 5

Part I Simplified forms	Part II Expressions for e
$Q_{sw} = \sqrt{\frac{K_F}{K'_s + K'_w}}$	$e_{sw} = \frac{K'_s + K'_w}{K'_c}$
$Q_{sv} = \sqrt{\frac{K_F}{K'_s + K'_v}}$	$e_{sv} = \frac{K'_s + K'_v}{K'_c}$
$Q_{wv} = \sqrt{\frac{K_F}{K'_w + K'_v}}$	$e_{wv} = \frac{K'_w + K'_v}{K'_c}$
$Q_s = \sqrt{\frac{K_F}{K'_s}}$	$e_s = \frac{K'_s}{K'_c}$
$Q_w = \sqrt{\frac{K_F}{K'_w}}$	$e_w = \frac{K'_w}{K'_c}$
$Q_v = \sqrt{\frac{K_F}{K'_v}}$	$e_v = \frac{K'_v}{K'_c}$

Coefficient of Permissible Variation in Production Quantities

From a comparison of the proposed forms given in Table 5, it is evident that the denominator for any one of the simplified forms will have a value smaller than that for the general form, because one or two of the major elements have been omitted. This means that any value for a production quantity Q_u obtained from one of the simplified forms will be greater than the value for the economic production quantity Q_e in the same problem. Consequently, this discrepancy in results, if evaluated, will serve as an index or measure for controlling the selection of the most suitable simplified form for a specific problem, provided that a definite maximum permissible limit of variation E_M[6] can be established to represent the existing conditions. Accordingly the coefficient E will be introduced to signify the permissible variation in the answer for a given case, the value of which can be determined from the equation

$$E = Q_u/Q_e \quad \ldots\ldots [4]$$

Coefficient of Allowable Variation in the Data

Furthermore, if the coefficient E is to be of any real value, its relation to the allowable variation in the data, resulting from the choice of elements for any simplified form, must be definitely established. Accordingly, if K' is allowed to represent any one, or a group of two, major elements used in the denominator and if

$$K'_c = K'_s + K'_w + K'_v$$

(i.e., the denominator of the general form), the coefficient e of allowable variation in the data may be expressed as

$$e = \frac{K'}{K'_c} \quad \ldots\ldots [5]$$

[6] The appropriate value for E_M for any problem can be obtained from Equation [27] or Table 4.

and then

$$Q_u = \sqrt{\frac{K_F}{K'}} \qquad \text{or} \qquad \sqrt{\frac{K_F}{e \cdot K'_c}}$$

Similarly if

$$Q_e = \sqrt{\frac{K_F}{K'_c}}$$

$$E = \frac{1}{\sqrt{e}}$$

and

$$e = \frac{1}{E^2} \quad \ldots\ldots [6]$$

Therefore, if E, in Equation [6] be replaced by its limiting value E_M, there will be some value for e which cannot be exceeded, and if a value for e is calculated from Equation [5] for various simplified forms and compared with the value for e from Equation [6], the most suitable form may be reliably selected. To illustrate how the various elements contained in each form may be represented by the coefficient e, the specific expression for e in each case has been included in Table 5, Part II. Moreover, at this point attention should be called to the fact that for a given variation in the answer a much larger variation in the data will be allowable, because e depends upon the reciprocal of E^2. As a result, greater latitude is permitted in the choice of a simplified form than could be if e were merely inversely proportional to E.

Index Ratios

If it were actually necessary to calculate the values for e in each case from the expressions given, little saving could be realized from the use of simplified forms. However, this can be avoided by employing a series of index ratios having a common denominator, each one of which will represent the relative importance of a particular element.

Accordingly let

$R_v = \frac{K'_v}{K'_s}$ and be the index for the space charge element K'_v

$R_w = \frac{K'_w}{K'_s}$ and be the index for the investment charge element K'_w on work in process

$R_s = \frac{K'_s}{K'_s}$ (a constant) and be the index for the investment charge element K'_s on articles in stores

$R_c = \frac{K'_c}{K'_s} = R_v + R_w + R_s$ and be the index for the denominator of the complete expression containing all elements.

Now upon substituting the full expressions for each one of these elements in these ratios, it will be found that certain groups of terms will cancel out, leaving only the important factors, so that the resulting simple expressions for these ratios may be used as a basis for the desired method of selection without involving any great amount of calculation, as previously discussed in connection with the calculation sheets. Hence,

$$R_v = \rho \cdot \frac{B}{c'} \qquad \text{where } = \rho \frac{v \cdot 2}{i \cdot h}$$

$$R_w = \frac{\left(1 + \frac{m}{c}\right) \cdot t}{\left(\frac{1}{Y_a} - \frac{k_p}{D}\right)} \qquad \text{where } k_p = (1 - 1/n)$$

$$R_s = 1.0$$

Two new terms have been introduced at this point to account for certain factors which are constant under specified conditions. The first, the plant ratio ρ is a constant for any plant as the terms v, i, and h have the same respective values regardless of the problem, and the second, the process factor k_p has a definite value for each type of process,[7] as follows:

For continuous production $k_p = \infty = \frac{1}{0}$

For semi-continuous production $k_p = 1$

For non-continuous production $k_p = 0$

For batch production $k_p = \left(1 - \frac{1}{n}\right)$

where n = the number of batches making up one process lot.

Method of Selection

Now that the identity of the index ratios of R_v, R_w, R_s, and R_c have been established, it is a simple matter to show how the resulting coefficient e for the variation in the data is obtained for use in the method of selection. If

$$e = \frac{K'}{K'_c}$$ by definition from Equation [5] and

R is allowed to represent the numerical value of any single index ratio or the combination of any two, in the same way that K' represents any desired grouping of the major elements, then

$$e = \frac{R}{R_c} \quad \ldots\ldots [7]$$

because

$$R = \frac{K'}{K'_s}$$

and

$$R_c = \frac{K'_c}{K'_s}$$

and the ratio R/R_c or e can be designated as the "form index."

By transposing this expression, it will be found that

$$R = e \cdot R_c \quad \ldots\ldots [8]$$

and if a value for e is used in this equation, which depends upon the maximum permissible limit E_M of variation (see Equation [6]), the resulting value for R will be the index for the elements that will be appropriate for use in the denominator of the desired simplified form. Accordingly, each index ratio should be compared, by inspection, with the general index R, and the one having a value slightly in excess of the value for R will indicate the particular element that should be retained in the denominator of Equation [3]. In case no single index ratio meets this requirement, some combination of two can be found that will, and then the two elements represented by these ratios will have to be used instead.

However, under ordinary conditions it has been found from experience that when the form index e has a value of approximately 0.666, the resulting simplified expressions will yield production quantities that will be quite satisfactory. Therefore, in drawing up the first part of the calculation sheets, an arbitrary index e_s, equal to 0.666 (or $^2/_3$), was introduced, in order to simplify the method and to dispense with the necessity of determining E_M and the limiting values for e and R for every problem. Of course, if any peculiar condition exists which may give sufficient cause to doubt the reliability of this assumption, these limiting values may be determined in advance. For this reason Part II of the calculation sheets has been prepared, but its use has been allowed to remain optional.

[7] For a more complete definition of each type of process reference should be made to that specific section of the original paper.

Short-Cut Method for Determining the Economic Production Quantity

If the actual variation from the true economic production quantity Q_e for any production quantity Q_u, obtained from one of the simplified forms, is measured by the coefficient E (see Equation [4]), the value for which depends upon the appropriate index e for the form used, it is quite possible to determine the correct value for Q_e directly from Q_u and thereby avoid recourse to the general expression (Equation [2]) for its solution, because

$$Q_e = \frac{Q_u}{E} \quad \text{(or)} \quad = \sqrt{e} \cdot Q_u$$

whereupon

$$Q_e = \sqrt{\frac{e \cdot K_F}{K'}} \quad \ldots\ldots [9]$$

or

$$= \sqrt{e_s \cdot \frac{K_F}{K'_s}}$$

$$= \sqrt{e_w \cdot \frac{K_F}{K'_w}}, \text{ etc.} \quad \ldots\ldots [10]$$

or, in fact, any other combination of elements. This can be carried still further if desired so that

$$Q_e = \sqrt{\frac{R}{R_c} \cdot \frac{K_F}{K'}}$$

by using the general terms R and K'.

The question may arise as to the need for the calculation sheets if such a short cut is available for obtaining the actual economic production quantity. The natural answer is that it is quite permissible to use this method if any time or effort can be saved. However, if one has gone so far as to obtain the index ratios required for determining the allowable variation, it would be more advisable to obtain the value for Q_u from K_F/K' in passing, and then gain the benefit from having a range of allowable variations in production quantities established, the limits for which will be E and unity. In the end this will provide an opportunity for greater control of production schedules in meeting fluctuations in the sales demand and a simplification of departmental routine that will far outweigh the value of increased accuracy.

Loss Due to an Uneconomic Production Quantity

The foregoing discussion has established the mathematical basis for the first part of the calculation sheets, and a similar basis must now be established for the second part. If a reliable index is to be developed for controlling the use of any simplified form it must be derived from some condition which represents the fundamental situation underlying a given problem. The one condition which will satisfy this situation may be found in the increase in cost over the minimum cost incurred by the production of a quantity varying to some degree from the economic quantity. This increase in cost is in reality a loss because it will reduce the normal profit expected in return from the sale of each article produced at a minimum cost. The unit loss L in such a case is equal to the difference between the ultimate unit costs U_u and U_e for an uneconomically produced quantity Q_u in the first instance and an economically produced quantity

Q_e in the second, the latter being the lowest unit cost obtainable. Hence,

$$L = U_u - U_e \quad \ldots\ldots [11]$$

In order to evaluate the loss, reference must be made to the general expression for the ultimate unit cost[8]

$$U = c' + \frac{F}{Q} + \frac{I_s}{Q} + \frac{I_w}{Q} + \frac{V}{Q} + \frac{D'}{Q} \quad \ldots\ldots [12]$$

where c' = unit production cost (as before)
F = total preparation charges
I_s = total interest charges on capital invested in inventory
I_w = total interest charges on capital invested in work in process
V = total space charge on articles in inventory
D' = total loss due to deterioration.

As this study is primarily concerned with the problem of simplification it will be permissible to omit the factors f, Δ, and θ from the expressions for the major items in the foregoing equation for reasons similar to those given in the first step, and thereupon the term D' will become zero. To avoid a repetition of the complex expression for U given in the original paper, Equation [12] can be evaluated for use in this discussion by omitting the foregoing factors and grouping the various items according to their relation to the quantity Q as follows:

$$U = \left[c' + \frac{F \cdot i}{2Y_a} \left(1 - \frac{Y_a \cdot k_p}{D} \right) \right] + \frac{F}{Q} + f' \cdot Q \quad \ldots\ldots [13]$$

where

$$f' = \frac{c' \cdot i}{2Y_a} \left(1 - \frac{Y_a \cdot k_p}{D} \right) + \left(\frac{m + c'}{2} \right) i \cdot t + \frac{v \cdot B}{Y_a} \left(1 - \frac{Y_a \cdot k_p}{D} \right) \quad \ldots\ldots [14]$$

or

$$= \left[K'_s + K'_w + K'_v \right] \cdot \frac{1}{Y_a}$$

It should be noted at this point that the item F contains all factors the total values for which depend upon the lot as a whole and are independent of the quantity, and that the term f' contains all factors the values of which are dependent upon the quantity when the lot is referred to. Now the actual expression for U_u and U_e can be obtained from the general expression for U (Equation [3]) by replacing Q by Q_u and Q_e, respectively, and when these expressions are substituted in Equation [11] and the indicated subtraction performed, the expression for the loss becomes

$$L = \left[\frac{1}{Q_u} - \frac{1}{Q_e} \right] \cdot F + [Q_u - Q_e] \cdot f' \quad \ldots\ldots [15]$$

Limits of Usefulness for Any Form

If an expression for Q_u is derived from Equation [15] in terms of the loss L and substituted in the expression for E (Equation [4]), it will be possible to obtain an expression for the limits E_l which will govern the application of any simplified form to a specific problem when the extent of this loss or the permissible increase in cost is specified. This may be accomplished by transposing the terms in Equation [15] so that

$$\frac{F}{Q_u} + Q_u \cdot f' = L + \frac{F}{Q_e} + f' \cdot Q_e$$

and by introducing the relation

$$f' = \frac{F}{Q_e^2} = \quad \ldots\ldots [16]$$

where

$$Q_e = \sqrt{\frac{F}{f'}}$$

which was obtained from Equation [2] by substituting the term f' for those items which it represents by definition (see Equation [14]), so that

$$\frac{F}{Q_u} + Q_u \cdot \frac{F}{Q_e^2} = L + \frac{F}{Q_e} + \frac{F}{Q_e}$$

Now this expression when multiplied by Q_u and equated to zero becomes

$$Q_u^2 \cdot \frac{F}{Q_e^2} - Q_u \left(L + \frac{2F}{Q_e} \right) + F = 0$$

and finally the desired expression for Q_u can be obtained by solving this quadratic equation. Accordingly

$$Q_u = \frac{(L + 2F/Q_e) \pm \sqrt{(L + 2F/Q_e)^2 - 4 \cdot F^2/Q_e^2}}{2 \cdot F/Q_e^2}$$

However, this expression can be put into a more workable form if Q_e is removed from each term (Q_e^2 from those under the radical) and placed at the beginning of the expression, so that when cleared of fractions it becomes

$$Q_u = Q_e \cdot \left[\left(\frac{L \cdot Q_e}{2F} + 1 \right) \pm \sqrt{\left(\frac{L \cdot Q_e}{2F} + 1 \right)^2 - 1} \right]$$

and then if the terms in the parentheses are replaced by the arbitrary relation

$$K_s = \left[\frac{L \cdot Q_e}{2 \cdot F} + 1 \right] \quad \ldots\ldots [17]$$

$$Q_u = Q_e \cdot [K_s \pm \sqrt{K_s^2 - 1}]$$

At this point it will be advisable to obtain the basic expression for the limits of usefulness E_l, before attempting to evaluate the expression for K_s, as that will involve setting up another relation for the loss L. Accordingly, if the expression given for Q_u is substituted in Equation [4], it will be found that Q_e cancels out and

$$E_l = K_s \pm \sqrt{K_s^2 - 1} \quad \ldots\ldots [18]$$

Naturally, as there are two roots for the expression within the radical depending upon the sign, the maximum limit E_M will be obtained by the plus (+) sign and the minimum limit E_M by the minus (—) sign. However, for the purposes of the calculation sheets only the higher or maximum limit will be used, as the value for the approximate or uneconomic quantity will be always greater than the exact or economic quantity.

Second Expression for the Loss

Until the terms represented by K_s have been replaced by terms, the values for which may be found in the data, or have been previously determined for other purposes, little practical value can be realized from the expression for E_l. As already stated, this will require another expression for the loss L which can be obtained by considering it as a function of the ultimate

[8] A full derivation of this expression will be found in the original paper. See footnote 2.

unit cost U_e and by introducing the loss factor λ, which will be explained later in detail when its utility has become more evident, so that

$$L = \lambda \cdot U_e \quad \ldots\ldots [19]$$

in which case the expression for U_e can be obtained from Equation [13] by inserting Q_e in place of Q. Moreover, for greater ease in handling the mathematics, certain other terms will be temporarily grouped by letting

$$K_u = \left[c' + \frac{F \cdot i}{2 \cdot Y_a} \cdot \left(1 - \frac{Y_a \cdot k_p}{D} \right) \right]$$

whereupon

$$U_e = \left(K_u + \frac{F}{Q_e} + Q_e \cdot f' \right)$$

or if the relation in Equation [16] is used again to eliminate the term f'

$$U_e = K_u + 2 \frac{F}{Q_e} \quad \ldots\ldots [20]$$

Accordingly, the second expression [19] for the loss can be rewritten as

$$L = \lambda \cdot \left(K_u + 2 \frac{F}{Q_e} \right)$$

and if this is substituted in Equation [17], an expression is obtained where

$$K_e = 1 + \lambda \left(\frac{Q_e}{2} \cdot \frac{K_u}{F} + 1 \right) \quad \ldots\ldots [21]$$

Problem Index

On the other hand, if the value for the loss L as given in Equation [19] had been directly substituted in the expression for K_e (Equation [17]) before the expression for the minimum ultimate unit cost U_e was inserted, it would have been found that

$$K_e = \lambda \cdot U_e \cdot \left(\frac{Q_e}{2F} \right) + 1$$

or

$$= 1 + \lambda \cdot \left[\frac{U_e Q_e}{2F} \right] \quad \ldots\ldots [22]$$

Herein lies a very interesting fact which is well worth a moment's digression in order to investigate its identity. If the symbol K_o is allowed to represent those terms which have been placed within the parentheses in Equation [22], so that

$$K_o = \frac{1}{2} \left[\frac{U_e \cdot Q_e}{F} \right] \quad \ldots\ldots [23]$$

K_o can then be defined as the ratio of the total cost $U_e \cdot Q_e$ of manufacturing a lot of an economic size, all contributary charges being included, to the total cost F of preparing for the manufacture of the lot. As the fundamental situation underlying any problem of economic production quantities is based upon the relative proportion of these two major cost items, K_o will henceforth be designated as the "problem index," and its numerical value may be used with certainty as one of the controlling factors in the determination of the limits of usefulness.

Evaluation of K_o

Accordingly, if the expression for U_e from Equation [20] be substituted into that for K_o (Equation [23])

$$K_o = \frac{Q_e}{2F} \left(K_u + \frac{2F}{Q_e} \right)$$

or

$$= 1 + \frac{1}{2} \cdot \frac{Q_e K_u}{F} \quad \ldots\ldots [24]$$

which, when the full expression for K_u is reintroduced, becomes

$$K_o = 1 + \frac{Q_e}{2} \cdot \left[\frac{c'}{F} + \frac{i}{2Y_a} \cdot \left(1 - \frac{Y_a \cdot k_p}{D} \right) \right] \quad \ldots\ldots [25]$$

This, of course, is the fundamental expression for K_o, but experience has demonstrated that the ultimate value of the parenthesis represented by K_u/F depends almost entirely upon the ratio c'/F, and for the purposes of the calculation sheet the terms

$$i/2Y_a \left(1 - \frac{Y_a \cdot k_p}{D} \right)$$

may be disregarded in computing the values of K_e or K_o. This can be easily demonstrated by the fact that if any one of the values for both Y_a and D most commonly encountered in such problems be introduced, the value of the parenthesis, where k_p will never be greater than unity, will evidently be almost equal to one, and when it is multiplied by the daily unit interest charge, the value of which is not often greater than 0.000666, and then divided by twice the average daily rate of consumption, the final total value for this group of terms will undoubtedly be too small to have any material influence upon the results. On this basis, then

$$K_o = 1 + \frac{Q_e}{2} \cdot \frac{c'}{F} \quad \ldots\ldots [26]$$

Should it happen that the economic production quantity Q_e had been determined in any case, prior to the use of the method proposed herein, and that it is now desirable to establish an economic range for production quantities, instead of having one inflexible quantity, either of the Equations [25] or [26] may be used as they stand. However, if a production quantity Q_u is to be calculated from some simplified form and K_o has not been previously determined, it will be necessary to eliminate Q_e from this expression. This can be accomplished by introducing the short-cut method, previously described, whereby Q_e will be replaced by items the values for which are readily available from the calculation sheets. Hence, from Equation [10], if

$$Q_e = \sqrt{\frac{R_w}{R_c} \cdot \frac{2 \cdot F}{(m + c')} \cdot \frac{1}{i \cdot t}}$$

Equation [26] becomes

$$K_o = 1 + \sqrt{\frac{R_w}{R_c} \cdot \frac{c'}{F} \cdot \frac{1}{2 \cdot i \cdot t \cdot \left(1 + \frac{m}{c'} \right)}}$$

and this expression has been used as the basis for the procedure given in Part II of the calculation sheets.

Factors Controlling the Limits of Usefulness

When the expression for K_o from Equation [24] is introduced into that for K_e (Equation [21]) in place of those terms in the parenthesis which it represents, it will be evident that

$$K_e = 1 + \lambda \cdot K_o$$

and that the limits E_l for the range of usefulness governing any simplified form will depend only upon the problem index and

the loss factor. This factor can now be defined as the proportional amount by which the ultimate unit cost U_u for an uneconomic quantity exceeds the minimum or ultimate unit cost U_e for an economic quantity. This statement may be illustrated graphically by the diagram given in Fig. 1 or mathematically by the expression

$$U_u = U_e + \lambda \cdot U_e$$

or

$$= U_e(1 + \lambda)$$

Actually, when a specific production problem is under consideration, as designated by the particular value for K_o, it will be found that this loss factor λ will be the one which controls the final choice of the limits of usefulness, because it is a measure of the extent to which the profit normally expected in return from the sale of an article when manufactured in an economic quantity will be reduced should an uneconomic quantity have been produced instead.

How the Loss Factor May Be Employed

Ideally, any production executive desires to manufacture the products of his company at the lowest attainable unit cost; this naturally will be the minimum ultimate unit cost U_e obtained only for an economic quantity, where $\lambda = 0$. In how many cases does this situation actually exist in industry? This may be answered for any specific case if the true economic production quantity is determined from Equation [2] and compared with the quantity which is now being used in production for each manufacturing lot. Many of these executives will be surprised at the divergence which exists in current practice from the ideal conditions. This situation can be arbitrarily improved, if not entirely corrected, by the use of the right-hand portion of the chart described in the next section and included with the calculation sheets in Table 4. If the actual quantity Q_a produced in each lot is introduced into Equation [4] in place of Q_u, the amount E_a by which it varies from the economic quantity Q_e can be easily determined because

$$E_a = \frac{Q_a}{Q_e} .$$

Then the loss factor λ_a which indicates the increase in cost for the quantity Q_a can be found by reading off the value of the curve nearest to the point of intersection of a horizontal line drawn through the appropriate value of K_o with a vertical line drawn from E_a. If greater accuracy is desired, interpolation between curves is permissible. The value thus obtained for λ_a can be used as a measure to guide the decision of executives in determining to what degree it can be reduced if it is not feasible at the moment to make it zero by the adoption of economic quantities for production purposes. Should some smaller value λ_d be decided upon, the procedure outlined may be reversed in order to obtain the value for the desired production quantity Q_d. In most cases it will be inadvisable to select too small a value for λ_d as no advantage can then be had from the use of either simplified forms or a range of production quantities.

In the first case, if a reasonable value for λ_d which will show a substantial increase in profits is selected, normal fluctuations in the rate of consumption and other errors arising from uncontrollable circumstances in production as well as the need for too frequent recalculation of the production quantities may be easily avoided, thereby simplifying departmental routine. It is impossible to predict in advance the most desirable value for λ_d without a detailed study of each case, as in most it depends upon the conditions peculiar to each type of industry or to the individual concern. Once this preliminary work has been accomplished for a number of typical cases and an appropriate value has been selected, no further recourse need be made to Equation [2] for the value of the true economic production quantity Q_e as the simplified forms will yield entirely reliable values.

Graphical Means of Solution

Now that means have been devised for determining the controlling factors λ and K_o for the limits E_l of the range of usefulness, some rapid method of solution must be provided which will not involve any of the implied calculations in order to obtain a limit for production quantities beyond which the resulting

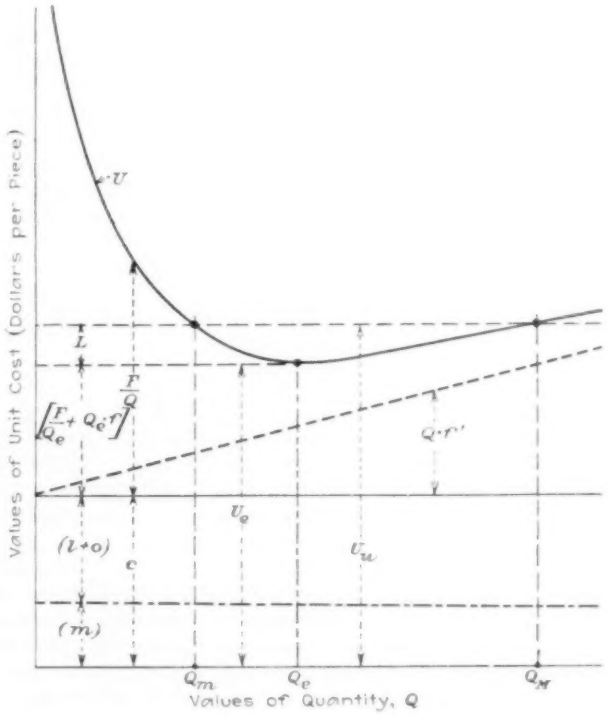


Fig. 1 Ultimate Unit Cost Curve U

increase in cost makes it inadvisable to go. This will be the maximum permissible variation E_M in the answer which can be obtained from the expression for E_l by using the positive (+) sign in Equation [18]. This equation when expressed in terms of these two factors just described becomes

$$E_M = K_e + \sqrt{K^2_e - 1}$$

$$K_e = (1 + \lambda \cdot K_o) \quad \ldots\ldots\ldots\ldots\ldots\ldots [27]$$

The simplicity of the expressions in Equation [27] immediately suggests a graphical form of solution (see Table 4), which was accomplished by plotting the values of K_e as ordinates and the values of E_M as abscissa, and drawing a series of curves each representing a definite value for λ. Such a chart is universal in its application; however, if the desired limiting value for λ_d can be selected by executive policy in advance, a similar chart can be prepared for use in a given plant, and then only the curve based on this value need be plotted, thereby relieving the subordinates in the production department of any responsibility in the choice of a correct value.

Applications of the Maximum Limit of Usefulness

Either of these charts for the maximum variation in the answer E_M can be used as described in a preceding section for

the determination of the value of λ_d in addition to completing the procedure outlined in the calculation sheets for determining the limiting value e_M for the form index e for any problem. In this latter case E_M must be transformed into e_M by use of Equation [6], where

$$e_M = \frac{1}{E_M^2}$$

but to avoid the necessary calculations the corresponding values for E_M and e_M have been plotted together on the bottom scale of the chart in Table 4 over the range that

$$E = E_M > 1.$$

The appropriate value for e_M can then be read off directly and compared with the values for e_a ($= {}^2/_3$) to check the accuracy of the method in Part I or used in Equation [8] to obtain a value for R which will represent the smallest value for any index ratio that may be justifiably used in selecting a simplified form to suit a specific case. In addition to this, E_M may be used to provide the upper limit Q_M for an allowable range of variation in production quantities which will permit greater latitude in the control of schedules and an adjustment for ordinary fluctuations in the sales demand, where

$$Q_M = Q_c \cdot E_M$$

or

$$= \frac{Q_a \cdot E_M}{E_a}$$

Minimum Limit of Usefulness

If such a provision will be of advantage, a still greater one can be realized if a lower limit or minimum allowable variation in the answer E_M is available. This may be determined from a similar chart prepared from the expression

$$E_m = K_e - \sqrt{K_e^2 - 1} \quad \ldots\ldots\ldots\ldots [28]$$

where K_e and naturally K_o would be the same as given for Equation [27] but where the minus (—) sign is used instead. However, it should be remembered that this minimum limit has no significance in connection with the selection of simplified forms, as all uneconomic quantities so derived will be greater than the economic quantity.

Conservation of Capital and the Limits of Economic Production

If a production quantity Q_M greater than the economic quantity is permissible, a smaller quantity Q_m for which the loss factor λ_l is the same is even more so as the allowable range of variation can be increased to include all quantities lying between for which the respective values of λ will be less than that for λ_l. Of greater importance, however, is the fact that the production of the smaller quantity Q_m will require less working capital than any other larger one, and the capital thus saved may be advantageously diverted to other gainful purposes. If capital can thus be conserved without impairing the expected profit to any greater degree, the quantity Q_m can be determined from the chart given in the calculation sheets Table 4 where the curves from Equations [27] and [28] have been combined.

The procedure in this case is quite simple, as the value for λ_d can be determined in the same manner as described, from the right-hand portion of the chart (Table 4). Then if the horizontal line through the appropriate value for K_e is followed over into the left-hand portion of the chart until it intersects with a curve having the same value for λ_d, the value for E_m will be found directly below this point on the scale at the bottom. Finally, if the values of E_M and E_m are read off and substituted in the expression

$$Q_m = Q_M \cdot \frac{E_m}{E_M} = Q_e \cdot E_m$$

where Q_M was determined from E_m in the right-hand portion of the chart, the value for the quantity which will conserve the greatest amount of capital will be obtained. Accordingly the limits of variation in production quantities will be Q_M and Q_m.

Determination of Savings

Another advantage can be gained from the use of the combined charts for E_M and E_m (Table 4) through the method it provides for determining the savings arising from any improvement in manufacturing operations. This will be of much assistance to production executives as it introduces a new tool for management to measure its proficiency and to aid them in their selection of the best methods. The savings which can be achieved from the production of the best quantity in any lot, the nature of the process being unchanged, may be determined by comparing the loss factor λ_a for the quantity currently used for production Q_a with the value of λ_d for the desired or proposed production quantity Q_d as obtained by the procedure outlined for a given product, the index for which is a specific value of K_e. In this case if the actual gain or savings G in dollars is measured by the factor g when

$$g = \lambda_a - \lambda_d \quad \ldots\ldots\ldots\ldots [29]$$

then

$$G = g \cdot U_a \quad \ldots\ldots\ldots\ldots [30]$$

On the other hand, if the method of manufacture of any product is improved at the same time, the value of K_e for the new process K_n will be different from that for the old K_a. In this case λ_a must be determined for values of $K_e = K_a$ and Q_a, and then if the horizontal line from the value of $K_e = K_n$ is followed as desired either to the right or left until it intersects the vertical line from Q_d, which will now represent the desired production quantity for the new process, the value for λ_d will be that assigned to the curve which passes through this point of intersection, whereupon the values of g and G can be obtained again from Equations [29] and [30]. It should be noted that the value of g with regard to sign is not affected by the fact that the value for λ_d was obtained from either the right-hand or left-hand portion of the chart.

Final Treatment of a Simplified Form

The fourth and final step toward simplification may be accomplished in two ways; first, by studying the arrangement of terms resulting from the substitution of the actual expressions for the major elements in the particular simplified form selected; and second, by expressing certain of these terms as constants, depending upon the industry and type of process. The first is entirely optional with the person making the calculations, but it will be found that a regrouping of the various items will reduce the final labor of calculation after the appropriate numerical values have been introduced and that, in certain cases, items which appear both in the numerator and denominator will cancel out or become combined. The second may be achieved by the proper selection of values for such terms as i, k, n or k_p, and r. Any one at all familiar with the handling of mathematical expressions would naturally perform these steps before attempting to compute the answer; however, this suggestion at least will not be amiss as it will serve to remind those interested that such treatment will always be of assistance.

Future Developments

The final form for the calculation sheets appearing in Tables 1, 2, 3, and 4 was adopted, as it is believed that the methods

developed by means of this study could be more readily applied in this manner to the practical problems of industry and that continued recourse to the theory could thereby be avoided. Of course it would be possible to devise other forms of presentation and a wholly graphical method would be quite practicable. It is hoped, as experience grows in the use of simplified forms, that numerical values can be assigned to the various index ratios which will definitely indicate the range of usefulness of each form, as it would be possible under such conditions to omit the procedure outlined in Parts I and II. Likewise, a further study of the values of the factors E_m, E_a, e_a, and λ will materially aid in the universal acceptance of these methods. In order to illustrate the application of the proposed methods, a sample calculation for a specific problem is given, Table 6. By reference to Tables 1 and 6 the identity of each numerical value used can be easily ascertained.

TABLE 6

(Data Obtained from a Paper Box Manufacturer for the Selection of Suitable Simplified Forms of the Economic Production Quantity Formula)

Items	Symbols	Units	Data
Unit production cost	c'	\$/pc.	0.0683
Unit material cost	m	\$/pc.	0.0521
Total set-up cost	M	\$	6.50
Total cost of issuing order	O	\$	0.48
Total preparation cost = $(M + O)$	F	\$	6.98
Unit production time	t	day/pc.	0.00025
Consumption rate	Y_a	pc./day	67
Interest rate per day	i	%/day × 1/100	0.000666
Space charge per day	v	\$/cu. ft./day	0.0001145
Unit of space occupied by article	B	cu. ft./pc.	0.909
Height provided for storage	h	ft.	10.0
Number of batches	n	....	1/0 = ∞
Process factor	k_p	....	1
Rate of deliveries to stores	D	pc./day	4000

In applying the data given in Table 4, reference should be made to the procedure outlined in the calculation sheets (Tables 1 to 4).

PART I — SELECTION OF FORM

Item 1 $\dfrac{0.0001145}{0.000666} \times \dfrac{2}{10} = 0.0344$

Item 2 $\dfrac{0.909}{0.0683} = 1.33$

Item 3 $0.0344 \times 1.33 = 0.456 = R_v$

Item 4 $\dfrac{1}{67} - \dfrac{1}{4000} = 0.01465$

Item 5 $\dfrac{0.00025}{0.01465} = 0.0170$

Item 6 $\dfrac{0.0521}{0.0683} + 1 = 1.763$

Item 7 $0.0170 \times 1.763 = 0.0299 = R_w$

Item 8 (a constant) $= 1.0 = R_s$

Item 9 $0.456 + 0.0299 + 1 = 1.486 = R_c$

Item 10 $1.486 \times \dfrac{2}{3} = 0.99$ (by inspection)

Evidently the index ratio R_s is the only one the value of which is greater than $^2/_3 R_c = 0.99$

Item 11 Therefore, the appropriate simplified form will be

$$Q_s = \sqrt{\frac{F \cdot Y_a}{\frac{c' \cdot i}{2}}}$$

because the parenthesis $\left(1 - \dfrac{Y_a}{D} k_p\right)$ can be omitted from the denominator of Q_s when Y_a + item 4 $(67 \times 0.01465 = 0.981)$ is greater than 0.9.

PART II — TO CHECK FOR FORM SELECTED AND TO DETERMINE THE LIMIT OF PERMISSIBLE VARIATION

Item 12 $\dfrac{0.0299}{1.486} = 0.02012$

Item 13 $\dfrac{0.0683}{6.98} = 0.00979$

Item 14 $0.02012 \times 0.00979 = 0.000197$

Item 15 $0.000666 \times 0.00025 \times 1.763 \times 2 = 0.000000587$

Item 16 $\dfrac{0.000197}{0.000000587} = 335$

Item 17 $\sqrt{335} = 18.3$

Item 18 $18.3 + 1 = 19.3 = K_o$

Item 19 Referring to the Chart (Table 4) and selecting the curve $\lambda = 0.001$ as a reasonable allowance for an increase in cost $= 0.675 = e$

Item 20 $1.486 \times 0.675 = 1.0030 = R$

Item 21 Comparing the value of R (item 20) with the value of R_s, the index ratio for the form used, it is evident that then nature of the problem demands, if accuracy is required, the use of the form which will include with the element depending on R_s the element which depends on the next largest index ratio, R_v in this case. However, as R only exceeds R_s by 0.003, the form as originally selected should be used, because the saving in effect by its use will be greater than any saving from increased accuracy ever could be.

Digressing to calculate the quantity Q to be used as the size of the production lot from the form

$$Q_s = \sqrt{\frac{F \cdot Y_a}{\frac{c' \cdot i}{2}}}$$

$$Q = \sqrt{\frac{6.98 \times 67}{0.683 \times 0.000666 \times {}^1/_2}} = \sqrt{\frac{935.32}{0.000045533}} = \sqrt{20{,}629{,}430} = 4542$$

which will be a satisfactory production quantity. To compare this with the true economic quantity if

$$Q_e = \sqrt{\frac{R_s}{R_c}} \times Q$$

then

$$Q_e = \sqrt{\frac{1}{1.486}} \times 4542 = 0.820 \times 4542 = 3724.$$

Now returning to the calculation sheets, if from

Item 22 $E_a = 1.21$ and $E_m = 0.822$

the allowable range of quantities for purposes of production control will be

$Q_M = E_M \cdot Q_e = 4546$ for the upper limit

$Q_m = E_m \cdot Q_e = 3061$ for the lower limit

which ought to provide sufficient latitude in arranging production schedules to account for ordinary fluctuations in the sales demand.

Discussion

B. COOPER. Before deciding upon the accuracy of the formula that should be used in determining economical production quantities, it is well to make a casual survey of the precision with which the principal terms in the formula can be determined. At the first glance it might be supposed that the consumption rate is the term in the formula that could be determined with the least precision. However, there are many conflicting opinions as to the methods of arriving at the other terms in the formula. Differences in opinion exist as to whether general overhead should be added to the unit production cost for calculating economic production quantities. The question of whether overhead should be applied to the preparation cost has never been definitely settled.

Machines are often set up by foremen and sub-foremen, who charge their time to departmental overhead. Mr. Kent, in his paper, states that business return on investment should be no less than one and one-half to three times the safe return to be realized on sound, marketable securities.

The precision with which the foregoing factors can be obtained makes the application of the approximate formula $Q = \sqrt{\dfrac{FYa}{\frac{C'i}{2}}}$, referred to in Professor Raymond's paper, of sufficient accuracy except where the time to manufacture a quantity exceeds one-third of the time to consume it, in which case the error in the economical production quantity based on the approximate formula will exceed 20 per cent and increase very rapidly with the increase in the ratio of the time to produce to the time to consume. When this ratio exceeds one-third, a very simple way of correcting the quantity calculated by the approximate formula is to apply precalculated correction factors, depending on the ratio of the time to produce to the time to consume. These correction factors are often important, for when this ratio is $^3/_4$ the calculated production quantity is only 50 per cent of what it should be.

Whether to use overhead on the preparation cost or whether to use a high interest rate depends upon the circumstances at hand. If the preparation cost is relatively high and the production costs

are low, as might be the case in heading, slotting, and thread rolling machines, the overhead should not be included in order to prevent excessive inventories, in most cases. The same results can be obtained by introducing different arbitrary constants into the formula for different departments. This procedure can be justified in view of the fact that no provision can be made in the formula for deterioration and obsolescence.

The application of economical production quantities becomes a little more involved when one has to deal with a series of operations. When the first operation is performed on an automatic machine with a high set-up cost and a low production cost, and the second operation is a hand operation with a high labor cost and a low preparation cost, the resultant production quantity will be uneconomically low for the automatic machine and too high for the hand operation. In this case it may be expedient to calculate and schedule two quantities with a provision for stocking the material between the first and second operations. It is generally found expedient to stock items before expensive finishing operations are applied.

In preparing economical production quantities for punch-press work the average number of pieces that could be run on the die before grinding is necessary should be taken into account as well as the average number of times that it may be necessary to grind the die in order to produce the economical quantity. When new quantities are introduced or radically changed, the quantity should be checked by the engineering department for contemplated changes in design, by the stock keeper for space and deterioration, and by the foreman for manufacturing difficulties.

Various means are used to simplify the mathematical calculations for determining economical production quantities. The writer had devised a special nomographic slide rule for this purpose which is being used in several plants. However, more important than the means of calculation is an intelligent study and application of the principles involved. A man in charge of this work should not only understand the theory involved, but should be familiar with manufacturing problems.

Few plants are so organized that all the necessary data for calculating economical production quantities are readily available. Many plants that have well-organized cost accounting systems and good inventory records from which consumption rates can be figured lack machine set-up costs. The machines are often set up by sub-foremen or day workers. Until the cost department is ready to supply the necessary data, set-up costs, production costs, and consumption rates should be estimated in order to get the system going. It might be well to establish a quota for the number of economical production quantities that should be figured, checked, and ready for issue each week. By this means one concern placed more than 6000 items on an economical production quantity basis in less than six months.

In addition to the direct saving in machine-preparation costs and inventory-carrying charges, the application of economical production quantities brings about more efficient plant operation.

SANFORD A. MOSS.[9] There was a time, within the memory of older engineers, when machinery was designed on the basis of experience as recorded in the brain of the designer without the formulas, theory of elasticity, and mathematical knowledge of the present day. We have passed beyond this stage so far as machine design is concerned, but have not passed beyond it so far as manufacture is concerned. For this reason the maximum of simplicity is necessary in the initial stages of application of mathematics to production control. Mr. Best's paper fully satisfies this criticism, and he gives a remarkably simple presentation; nevertheless he does not seem to have made any sacrifice so far as utility is concerned.

A usual factor in an economic lot formula is the cost of preparation or set-up charge. This seems to be constant for Mr. Best's case, so that it does not appear as a variable. In order that it may be seen just how it disappears as a variable, it would be desirable if Mr. Best would give the steps in the deduction of his formula.

Professor Raymond's paper seems as complicated as Mr. Best's is simple, and it is questionable if such a degree of complication is warranted in the present state of the art. If one set a professor of theory of elasticity to making a design for a wheelbarrow, he would achieve a certain result, but a useful result could be obtained by much simpler methods. We of course desire the accuracy obtained by the use of all of the variables which Professor Raymond gives, but have the difficult problem of obtaining such accuracy by much simpler methods than those in his paper.

Mr. Kent's paper gives a very interesting introduction, but just when one looks for a means of applying the principle so well set forth in the form of formula, the paper terminates. It would be desirable if some of the formulas used by Mr. Kent could be afforded.

W. L. JONES.[10] From time immemorial authorities on the subjects of production scheduling and stock maintenance have preached rapid turnover, but have nearly always further stated that in placing orders for stock one should take into consideration such factors as storage space required, value of the article, and cost of setting up machines or placing orders. Frequently the continual drive of management and the bankers on capital turnover has caused the preparation costs to be lost sight of and ignored.

Too often the attempts of pure judgment, based only on observation, to keep a true balance between preparation costs and investment charges have failed because the one was hidden in the general labor costs and the other fully exposed to view and criticism in the financial statements.

The mustering of scientific reasoning and mathematical formulas to bring to light in a form as positive as the balance sheet the cost factors involved in ordering and the effects of incorrectly balancing those factors has done much to convince management that investment in materials of manufacture can be more than a necessary evil endured for the sake of insuring production continuity.

General adoption of the principles of economic production quantities has brought into use nearly as many formulas as there are users, formulas varying in complexity from Mr. Best's simple equation in three variables to Professor Raymond's radical embracing most of the letters of two alphabets. The tendency is as would be expected—toward simplification. The approximations in use apparently arise from two considerations—first, for ease of calculation; second, to permit the use of data readily available for computation. For rapid slide-rule calculation it is desirable to eliminate as many as possible of the additions and subtractions. For the second consideration, it is usually unwise, as Professor Raymond says, to attempt to evaluate such intangibles as an obsolescence coefficient, and under some conditions other factors are equally indeterminate. Every manufacturing problem has its own best approach; it is the problem of those entrusted with the administration of production quantities control to arrive at the formula best suited.

It is toward this necessity for the choice of one or more approximate formulas, according to the demands of the many factors involved, that Professor Raymond's paper makes a valuable con-

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[10] Order Planning Department, Western Electric Company, Inc.

tribution. It is only by a complete analysis of all possible conditions of manufacture and all of the elements that are affected by lot sizes that general or specific conclusions of value to the manufacturer may be reached.

While the writer feels that many of the steps specified by Professor Raymond in his procedure for determining the allowable approximations are more complicated than many would find it profitable to follow, particularly if the product of manufacture is of great variety, still he is sure that only by a thorough understanding of all that the author has shown in detail can one be certain that the more arbitrary approximations that may have to be decided upon from day to day are well founded and safe to apply.

PAUL N. LEHOCZKY.[11] The author's formula is no doubt valuable from the mathematical and the scientific standpoint. The emphasis on saving is important; the method of illustration good.

Formulas are dangerous, however, especially when used by individuals who cannot or who do not care to investigate them. A general rule of this kind automatically creates the assumption that it will hold for any case and that the factors appearing in it are equally general. This, however, is not the case. No two plants will have the same factors present, considering factors from the weighted standpoint.

A slight shift in the determination of, let us say, the factor F will cause a serious error in the final result. This raises the problem of uniform accuracy in determining the factors. Highly accurate factors are useless when others represent mere guesses. This is especially the case if the added complication of relative importance is also considered.

This type of formula concentrates on the development of high efficiency in one certain function of manufacturing. An effort to follow the formula to the letter may lead to serious changes in the existing balance of the plant. These changes, probably negative, will not appear in the savings as expressed by the curve. It may therefore well be that an apparent saving has in reality caused a loss, not foreseen by the man who followed the dead letter of the formula. Application along lines of the method of reasoning evolved, rather than the formula, should be urged.

GORDON PENNINGTON. The author's effort to simplify the fundamental formulas for economic production quantities deserves strong commendation as a step in the right direction. However, it is going to be necessary to carry this simplification very much further than the author has carried it before manufacturing executives, generally, will make use of these formula.

Successful production men as a class are not accustomed to relying upon mathematical formulas, and they will not do so unless these are reduced to such simple terms that no risk of error or misinterpretation is involved in their use.

Simple formulas can be arrived at either empirically or mathematically. The future standing of scientific production lot control depends upon which of these methods is followed.

The empirical method has been used by Mr. C. H. Best. From his twelve years' experience he has developed, arbitrarily, a simple formula for production lots which, judging by his success with it, has proved accurate under the special set of conditions applying in his own particular case. His formula, however, and in general all formulas developed empirically are subject to the very great disadvantage that they are not applicable to the problems of other concerns nor can they safely continue to be used if the production methods upon which they are based are changed. Empirical formulas are thus dangerous because of the ever-present possibility that they will be used under conditions to which they do not apply.

To illustrate: Mr. Best found it unnecessary to make his formula depend upon the preparation cost. Evidently this factor is practically a constant for all of the products manufactured by Mr. Best's company. But if his company were to adopt new production methods which, while decreasing the direct labor cost, considerably increased the preparation cost, it is evident from common sense as well as mathematical considerations that larger batches should be processed to secure the greatest economy. If such a change in production methods should occur while Mr. Best is still setting lot quantities for his company, the writer has no doubt that he would promptly change his formula, but if in the meantime some one else has taken his place who was not as familiar with the limitations of the formula, it is very probable that the latter would not realize the need for a change, with the result that he would either materially decrease the company's profits or, realizing that something was wrong with the formula but unable to determine just what, would give up all attempts to calculate the proper batch sizes.

The danger involved in the use of empirical formulas is that they will be used by many who do not understand their limitations and they will lead to serious losses which will unjustly discredit scientific production lot calculation. Empirical short cuts to simplification cannot be too strongly discouraged.

The only safe way is to proceed by the method which Professor Raymond has used; that is to start with the fundamental factors which are common to all industries and from these to obtain formulas which are universal in their application. These can be mathematically simplified for any clearly defined set of conditions into expressions which will still be universally applicable within the limits set and can therefore be safely used by any one who understands what these limits are. The criticism of the author's paper is simply that he did not go far enough, although this method is the only one which can be safely followed.

As a matter of fact, the mathematical solution for the most economical production lot, even in its general form, is much simpler than the paper suggests. And in all cases where production lots are delivered into stores in a single batch, and where the annual sales in dollars are more than ten times the preparation cost, the general expression can be reduced to the following form:

$$L = \sqrt{\frac{2AD}{kB}}$$

where L = the economic lot quantity
A = preparation cost in dollars
D = demand in pieces per annum
B = unit cost in dollars (not including preparation cost—this will include labor, material, and burden)
k = the sum of interest, obsolescence, deterioration, and storage charges, expressed as a fraction (not per cent) per annum of the total piece cost (k will usually have a value between 0.12 and 0.36).

The foregoing formula is an approximation, but it is a mathematically sound one, and when applied within the limits given, it gives results which are as accurate as any method of cost accounting in general use and can be applied equally to the production of anything from watch parts to furniture. It may be added that, if the example given at the end of the paper is solved by means of the foregoing formula, the result, which will be 3200 pieces, will be slightly more accurate than the author's solution

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of 3724, although the difference in the final cost per piece is only one-tenth of 1 per cent in this case.

This brings up the question of when accuracy is necessary in production lot control. Obviously it would not be highly important in the case which the author has cited, where a difference of 15 per cent in the lot quantity only affects the total cost one-tenth of 1 per cent. There are other cases, however, in which the difference between a fair guess and an accurate calculation may represent the difference between red ink and extra dividends. Manufacturing executives are first of all interested in knowing when to apply scientific production lot control.

The rule is a very simple one. When the amount of the annual sales in dollars is more than a thousand times the preparation cost for one lot, a good production man's judgment is sufficiently accurate. When the amount of the annual sales in dollars is less than a thousand but more than a hundred times the preparation cost for one lot, lot quantities should be calculated approximately; that is, a mathematical solution should be made for a few typical parts, and the lot quantities for other parts may the safely be set by comparison. When the ratio referred to is below one hundred, but above ten, calculation in each case is advisable, but the formula given is sufficiently exact. When this ratio falls below ten, the general formula should be used. When the risk of deterioration or obsolescence is high, these ratios should be doubled.

The general formula, by the way, can be expressed in the form:

$$L = \sqrt{\frac{A^2}{B^2} + \frac{AD}{KB}\left(\frac{NP}{NP - D}\right)} - \frac{A}{B}$$

where N is the number of working days per year and P is the production in pieces per day, the other symbols being the same as already given. This formula is mathematically exact for all cases.

It will be evident, from the consideration of this rule, that the real field for scientific production lot control is where a large variety of products is manufactured in relatively small quantities, but with modern production machinery, which usually requires considerable set-up and planning for each lot. The manufacture of service parts is a field which particularly calls for mathematical control. Contrary to the common belief, quantity production, least of all, requires mathematical control.

Wherever accurate calculation of production lots is justified, it will usually prove just as important to calculate the reorder point. The production engineer is just as much interested in determining when to reorder as how much to order at a time, and, particularly in the case of service parts, the proper selection of reorder points is usually important, if an excessive inventory, on the one hand, or frequent emergency shop orders to supply deficiencies, on the other hand are to be avoided. (Those who are interested in this subject will find a full discussion of it in the March, 1927, issue of *Manufacturing Industries*.)

In conclusion the writer would like to point out that the really difficult and intricate part of the problem is to determine accurately for any given company the proper value for the factors, such as the preparation cost and the obsolescence and storage charges, which govern their particular problem. There is where the process of mathematical analysis is usually necessary. When this part of the work has been properly done, it is usually possible to express the results in a form even simpler than that suggested, often merely as a table which any production clerk can use with safety.

As a final suggestion, in the interest of simplification, it is recommended that all reference to a "minimum cost quantity" as distinguished from an "economic production quantity" be avoided. As the author is understood, he means by the former the proper size of a lot *if* obsolescence and deterioration are not taken into consideration, but as in practice these factors cannot be ignored, the "minimum cost quantity" is of purely academic interest, and reference to it had best be omitted.

THOMAS D. PERRY.[12] Have any standards been developed to add to the fundamental formulas a variable for single and multiple sizes, when such are feasible?

In the case of plywood, as the size or area of individual plies increase (above a certain point) the raw material increases in unit costs. At the same time the labor of preparing and laying larger pieces is not materially greater than for smaller pieces, and therefore unit costs diminish. These are seldom compensating variables, and often are important factors in determining the size of runs.

JOHN YOUNGER.[13] The author has done a splendid piece of work in calling attention to the large sums of money lost in putting improper lots through our factories. It is to be wondered, however, if he has not made his work too mathematical for the average production man. The writer is fully convinced that the use of mathematics some day will play a necessary part in the routine of production planning just as it now does in design, but until that day comes we must have our mathematics as simple as possible and also as much of it as possible.

It is also a question as to whether the mathematics should be presented in graphic form. The writer believes this is preferable.

Further, it is a mistake to search after too much accuracy, as therein lie danger and confusion. Complicated variables should be avoided as much as possible.

For the foregoing reasons, the writer prefers a simple solution such as that which follows:

Assume production capacity of P, units of product per year.
Assume a salable quantity of p.
Assume raw material cost m per piece.
Assume final product cost M per piece.
Assume interest on both at 6 per cent per annum.

Product will be produced in $\frac{\text{salable quantity, } p,}{\text{production capacity, } P}$ fraction of a year in one lot.

Interest on raw material while in process will be 6 per cent $\times \frac{p}{P} \times m$.

Interest on finished product while in storage will be 6 per cent $\frac{1}{2}\frac{P - p}{P} \times M$.

The fraction $^1/_2$ is brought in as it is expected that on the average all the product will be sold during the total period; then interest can be charged up for one-half the amount during the whole period or all the amount for one-half the period.

The total cost then becomes $(M + m)\ p$ plus $\frac{6 \text{ per cent}}{P}$ or $(mp - M\ P + M\ p)$ for one lot.

Work this out similarly for two lots, and three lots, and four, and five, and six and thus plot a curve which, it will be found, is parabolic, such as the author's, and very similar in form and position. This curve has months as the base, 12 months representing one lot per year; 6 months, two lots; 4 months, three lots; 2 months, six lots; etc. The vertical ordinate is cost. The lowest

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point of the curve represents the point where the most economical lot size is reached.

The foregoing reasoning involves very simple mathematics and has the additional advantage of placing the reasoning in graphic form.

$$Mp + \frac{6 \text{ per cent}}{P}\left(pm + \frac{PM}{2} - \frac{pM}{2}\right) =$$

Authors' Closure

Mr. Raymond. All recent attempts to study management problems through the use of methods which are familiar to the engineer seem to be condemned from the start because of the extended use of mathematics as a device for expressing in concrete form certain fundamental relations which might otherwise require pages to describe. Industrial executives seem to abhor any approach to the problems of management which savors of technical details, and in most cases they resort to the statement that management in practice is too intangible for such scientific treatment. Up to the present, management has largely achieved its successes by attacking the most obvious difficulties which were certain to yield a substantial return for the effort employed and show in the company's balance sheet at the end of the year a satisfactory increase in profits.

As time progresses and more of these difficulties are overcome, an increasing amount of effort will be required to obtain the same proportionate degree of success. Even at best a stage of diminishing returns will set in unless management is provided with more precise tools, in order to continue the search for those hidden costs which must eventually be brought to light if the present rate of progress is to be maintained. If this is to be done, the practical industrial executive must be willing to accept the product of research in management and accustom himself to the newer modes of thought, even though it may have to be expressed in terms not always familiar to him.

Any study of this sort, if it is to be of general application, must present the fundamental relations which control the general problem; only after these are unquestionably established is it wise to attempt to interpret the conclusions in terms of a specific problem, because in the natural simplification, which will necessarily follow, definite assurance must be provided that any omission or permissible deviations will not introduce errors of a more serious nature.

A mathematical formula will be of considerable advantage in this respect, because it can be employed to give full expression to the basic relationships in a symbolic form so that they can be appreciated at a glance. The presence of a formula should not necessarily imply lengthy or tedious calculations, because in the initial stages of its use the ultimate gain will come from the applications of the principles involved as interpreted for a specific case, and actual values will only be required in the later stages when it becomes necessary to establish a measure or a standard of performance as a guide to those responsible for the continuance of achievement.

In any general study such as this, certain factors peculiar to some industry undoubtedly will not be properly emphasized. However, if those interested bear in mind that when the factors, whatever they may be, are classified according to total costs, unit costs, and constants, the first two of which are the major components of the numerator and denominator, respectively, of any formula for the economic size of a production lot, little confusion will be encountered in the solution of the problem. Naturally, if the utility of any such scheme of control is to be eventually "sold" to the highest executives of the company, it must be first reduced to its simplest proportions. This can be done only by those who are thoroughly familiar with the practical side of the problem, and by reducing it to a routine form through the use of special tables, charts, or slide rules.

Mr. Pennington has added much by his proposal for selected ranges, according to the relation of the preparation cost to the cost of goods sold, for designating the degree of accuracy required in selecting an appropriate expression for determining the best lot size. His remarks illustrate admirably the conclusions which can be drawn from a practical application of Table 4 accompanying the calculation sheet.

Mr. Jones has raised in his discussion a very interesting point with regard to joint economic production quantities; that is, the situation where a fabricated part is composed of elements the manufacture of which, for convenience, cannot be considered separately. In this case, the preponderance of evidence still shows, as a result of recent study, that in all probability each element should be produced in quantities that are determined distinctly for itself and not for all combined. The deciding factor in such a situation will always be the one which will yield the lowest minimum cost for the type of processes employed. Analogous to this is the case of single or multiple sizes or strips processed at the same time. Here, too, the best lot size will be obtained for the lowest cost process.

In manufacturing to order and not to stock, economic production quantities cannot be directly applied, because the chief factor in the economic balance, in opposition to the preparation cost, is lacking; that is, the cost of capital invested in inventories, because in the first case goods are produced only as the customer requires them.

However, it will be advantageous to analyze the manufacturing problem on the basis of economic quantities and determine whether it would be wiser to obtain a year's contract, even at a lower price, than to incur the otherwise high cost of preparation. Rush orders, similarly, have no relation to economic lots as they are distinctly an expedient to remedy some emergency. Nevertheless, the situation can be improved if the machine load budget is constructed on the basis of economic quantities, as then these rush orders can be more easily processed without incurring too serious an interruption in the prearranged manufacturing schedules.

In answer to several questions raised, in connection with the deviation of the empirical formula presented by Mr. Best, it may be said that its fundamental form is similar to the one for the general formula the author has proposed, except that the elements for work in process and storage space have been eliminated. Mr. Best has not omitted the preparation charge, but owing to the fact that he has derived special formulas for substantially each individual product, of which this is one, the preparation charge has been evaluated along with all other items which could be assigned constant values and appears in the coefficient outside the radical.

Depreciation and obsolescence are two other factors which may have at times an important relation to the economic lot size. The former can be accounted for as a loss directly attributable to the ultimate unit cost, whereas the latter, owing to the uncertainties which control its occurrence, must be treated in an entirely different manner. The effect of obsolescence is to make worthless the amount of capital which has been invested in articles that become unsalable owing to a shift in the sales demand. To protect such capital, obsolescence must be provided for by the production of a lot which requires the least investment to attain a reasonably low manufacturing cost, because there the smallest amount of capital will be endangered at any one time. This raises a very important question as to whether production at minimum cost is the most economical.

Further research has proved that the economic quantity is not the minimum cost quantity and can be a very much smaller one

without impairing the gross profit which would otherwise have been earned if production had been based on the lot size for minimum cost. To demonstrate this would require the preparation of another long paper, but for the moment it is well to bear this fact in mind, as it shows conclusively the value of research methods applied to management. It is problematical in the majority of cases whether the ordinary executive, who is occupied with the details of a particular business, would have the time available to devote to the discovery of this fact by himself unless there had been some extraordinary incentive, because such men have quite enough to do without stopping to question supposedly well-established principles as apparently basic as production at minimum cost.

MR. BEST. In his discussion, Mr. Sanford A. Moss suggests that it would be desirable if the steps in the deduction of the formula were presented.

There are fifteen production departments in the plant of Eli Lilly and Company, and each department produces a line of merchandise by processes practically unrelated to the processes employed in the other departments. Instead of developing a general formula for economic production quantities, it seemed expedient to develop individual formulas for the different departments. Variations in procedure within a department would make necessary one formula for each classification of processing in that department. There are 64 formulas in use in this office, each one being applicable to only a portion of the products that are made.

Equipment "set-up" or "make-ready" costs are not factors of importance in our costs. However, for lot-size determination there are similar costs that must be considered. Standardization, assays, chemical analyses, and tests upon animals form similar costs that remain the same per lot regardless of the lot size. Planning office supervision, perpetual inventory recording, and an expensive reweighing and checking system in the raw material supply department form three other elements of cost that are constant per lot regardless of lot size. Each of these costs is expressed algebraically.

All the foregoing costs are carefully determined for each of 64 classifications of product, but in the simplified formula given in the paper all these items appear in the constants. The only variation in the formulas for the 64 classifications are variations in constants.

The variable costs that enter each formula are actual processing costs, cost of actual storage space occupied, and interest, taxes and insurance on the investment. These variable unit costs are carefully determined and expressed algebraically.

Now the first derivative of the algebraic sum of all these components of the unit cost is set equal to zero to arrive at the formula for determination of the economic production quantity.

A nomographic slide rule for each of the 64 formulas makes the job of the clerk who determines lot sizes a very simple matter. The clerk needs to know only:

1 Unit material cost
2 Number of units sold per year
3 Classification.

Answers to items 1 and 2 are always at hand when a production order is being issued. The name of the article that is to be processed and the blue-printed working formula identify the classification (item 3) very positively.

Now the selection of the proper lot-size formula is solely dependent upon classification of the product. It is not necessary to make any adjustments in any formula.

For instance, a production order is to be issued for a coated tablet that is scheduled for a triple rotary compression machine. The proper nomographic slide rule to use is headed "Compressed coated tablet—triple rotary." A straightedge is placed upon the chart, and the proper lot size is read direct. The clerk does not need to know that there is a formula. He does not need to know how to extract the square root.

The extreme simplicity of the routine operation of this system of lot size control is of course the chief virtue of the system. The local problems have been solved in a satisfactory manner. The system has accomplished rather outstanding results. These are the merits.

On the other hand, considerable time was required to originally set up the framework of the system, and considerable time is required to incorporate changes in procedure into the formulas.

This method of attack might suit some cases and be entirely unsuited to others.

MAN-52-3

Aeronautical and Automotive Service Mechanics

By A. D. ALTHOUSE,[1] DETROIT, MICH.

This paper describes the training courses for airplane and automobile mechanics as taught at the Cass Technical High School, Detroit, Mich. They have more than doubled the minimum training requirements for airplane mechanics as set forth by the United States Department of Commerce. The course for airplane-engine mechanics includes specifications of various types and gives shop work in tuning, adjusting, and overhauling engines. The course gives skill in the use of various hand tools and also teaches technical details. Automotive training includes machine fitting, internal-combustion engines, chassis details, automotive electricity, welding and engine testing.

THERE are certain fundamental things to be considered in any mechanic's training. These things and their bearing upon modern trade training may well be studied by comparing the trade-training methods in use before the World War and the methods in use today. Before the war many youngsters were taken into the mechanical industries as apprentices. The ages of these apprentices varied from 14 years up to 18 or 20 and the school grades from the sixth to the tenth. These boys worked in the shop under a competent mechanic who taught the youngsters the use of tools and the processes with which they should be familiar. Such subjects as mathematics, drawing, and science were given in regularly organized classes. These subjects were made practical, and the problems were applied directly to the work done in the shop.

The war and certain labor legislation upset this apprentice organization in Detroit almost entirely. High wages paid for work that could be learned very easily made the youngsters less eager to enter apprenticeship training. Compulsory school laws have made it necessary for the youngsters to attend school until 17 years of age or until they have completed the tenth grade. Boys leaving school at this age are not so satisfied with the wages usually paid apprenticeship boys, and they seek production work or some employment that will be more immediately remunerative.

The Michigan labor laws also have had a decided effect upon the apprenticeship systems. Due to a peculiar wording of the employers' liability act prior to 1927, employers of children under 18 years of age were put to a great disadvantage in the event of any accident occurring to young employees. The act contributed to the breaking down of the old apprentice system. During the last two years, however, some modifications have been made in the law, making it easier for employers to hire children under 18 years.

As a result of these school and labor laws, more of the burden of training for the industries has been thrown upon the public schools, and particularly upon the technical, trade, and vocational schools.

The technical school in Detroit began giving trade training in the evening classes. Whenever sufficient demand warranted the action, a day class would be started in that subject. This action soon brought to the front the type of training that might best be given to the youngsters in the day-school classes. In a large measure the evening schools have shown the way for the day-school work. Before beginning any new day-school course it is usually tried out in the evening-school classes.

Training of Aeronautical Mechanics

Due to the activities of the Department of Commerce, Aeronautics Branch, the objectives of this type of training are very well defined. The Department of Commerce issues three distinct types of licenses for pilots and mechanics, and the requirements for licensing each are very definite. These licenses are for pilots, airplane mechanics, and airplane-engine mechanics. The Aeronautics Branch of the U. S. Department of Commerce has prepared a booklet of "Air Commerce Regulations" (Aeronautics Bulletin No. 7) in which are set forth the exact requirements of training for any of the Department of Commerce licenses.

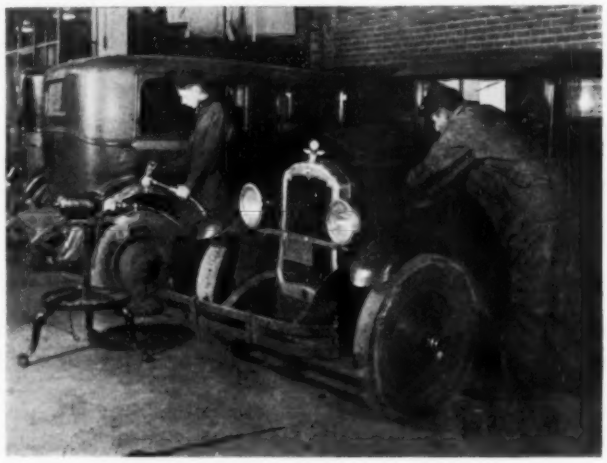


Fig. 1 Shop in Wilbur Wright Cooperative School, Detroit (This illustration shows the boys at work on automobile repair jobs. This shop is equipped to do all kinds of automobile service work.)

For a pilot's license the specified subjects are airplanes, aircraft engines, meteorology, navigation, parachutes, air-commerce regulations, and instruments.

In Detroit definite unit courses covering each of these subjects have been established in the evening schools. The public schools do not give flight training, but do give all the necessary subjects to pass the theoretical part of the Department of Commerce examination for all grades of pilots' license.

For the licensing of airplane mechanics certain training in specified subjects is demanded. However, the minimum requirements set forth by the Department of Commerce are not nearly sufficient. The prospective airplane mechanic must first be a

[1] Cass Technical High School.

Contributed by the Committee on Education and Training for the Industry and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 15, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

mechanic; that is, an accurate, conscientious, and reliable workman who takes pride in doing a piece of work well.

In order to train such a mechanic it is necessary that he do all of the usual airplane jobs several times under competent supervision and instruction, and not that he merely be told how to do them. A first-class airplane mechanic should have the following qualifications:

He should be a competent acetylene welder on tubing and thin sheet metal. He should be a better than fair woodworker, and he should be an expert wireworker on both solid wire and stranded cable. He should have some ability as a draftsman and be able to read blueprints. He should have had considerable practice in rigging flying ships, and he should have a fair understanding of the essentials of metallurgy as it concerns the metals with which he works.

To illustrate why this training is essential, take for example the repairing of a steel-tube fuselage that has been injured so

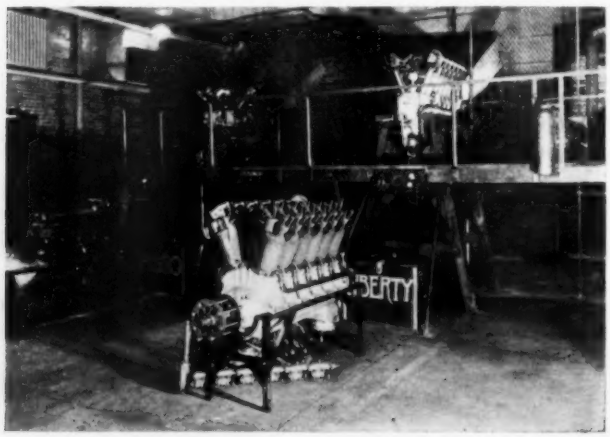


FIG. 2 AIRPLANE-ENGINE LABORATORY IN CASS TECHNICAL HIGH SCHOOL

(The running engine on a small balcony is supplied with water, gasoline, and oil from pipes under the balcony. The instrument panel contains the controls and the usual engine instruments. A duplicate engine used for assembly practice is shown in the foreground.)

that a section needs repairing. The owner must submit to the Department of Commerce in Washington a drawing or blueprint of the repairs that he proposes to make, together with complete specification of the sizes, length, and alloys of the material that he purposes to use. The engineering staff of the Department of Commerce examines these plans and specifications, and carefully checks them; and if they are approved, a set of the plans are returned to the owner, with corrections if necessary, and a duplicate set is sent to the Department of Commerce inspector for that area. The owner is then authorized to have his mechanics make the repairs, and when they are completed, the inspector determines if the repairs have been made according to the specifications furnished. It is evident that a mechanic properly prepared to do this job needs a very broad training.

In the Detroit system, the training of airplane mechanics is given in two courses in airplane construction and two courses in acetylene welding. The welding courses include some metallurgy. A special course of mathematics relating to aeronautics parallels the airplane-construction work for the student who needs more training in mathematics.

The Detroit courses have more than doubled the minimum training requirements as set forth by the Department of Commerce for airplane mechanics. This is done to more nearly fit the student for airplane work.

The training for the airplane-engine mechanic is similar. The student must be familiar with engine specifications and have had a great amount of experience in tuning, adjusting, and overhauling aircraft engines.

The courses for airplane-engine mechanics in the Detroit evening classes divide the engine work into three parts. A preliminary course in engine principles is offered first. This course gives the student experience in dismantling and assembling modern aircraft engines and gives training on the fits and clearances allowed in aircraft engines as well as instruction on timing and firing order.

The second course deals entirely with electrical work, such as ignition, starting, and lighting. A large portion of time is spent on high-tension magnetos.

The final engine course is engine testing, which is done entirely on running engines. For this subject five popular aircraft engines are mounted on stands, with propellers and guards, complete in every detail. Running adjustments are made on valves, ignition systems, and carburetors, as well as on valve and ignition timing. Some dynamometer work is done in order to teach the measurements of horsepower, torque, brake mean effective pressure, and other factors of engine performance. The aim of this part of the work is not to develop research ability, but merely to work with engines under load, and to develop the students' ability to detect and repair minor faults that will appear only under full-load operation.

In many ways the engine courses are the most satisfactory ones offered because the men are able to obtain exactly the information they need for employment in the industry as airplane-engine

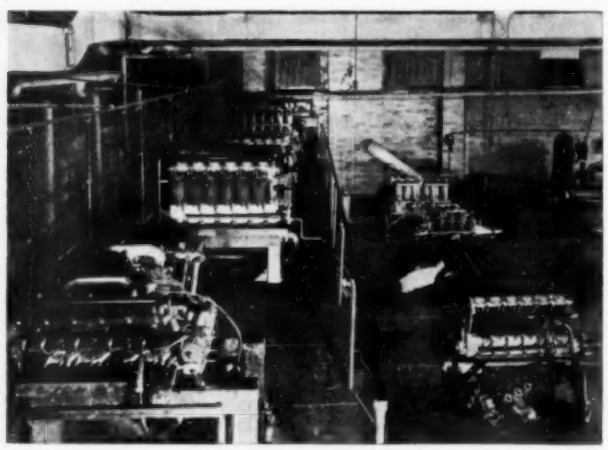


FIG. 3 SECTION OF AIRPLANE-ENGINE TESTING LABORATORY IN CASS TECHNICAL HIGH SCHOOL

(The running aircraft engines are mounted on a stand, with a guard between the propeller and the engine. These engines are used for running adjustments and timing.)

mechanics. A great number of men now employed in aircraft-engine work, but who have not as yet obtained the aircraft-engine mechanic's license, join the classes in order to get the information necessary to pass the theoretical part of the Department of Commerce examination.

Undoubtedly the public schools can be of great assistance to the aero industry in training men for aeronautical service, and this training may best be given by unit courses covering some specific work for which the particular community manifests a need.

Before aeronautical classes were offered in the Detroit public schools, a conference was held with the leaders in the aeronautical industry of the Detroit area, and the work offered was with their cooperation and sanction.

It might be mentioned for the benefit of public-school systems contemplating the establishment of aeronautical courses that both the Daniel Guggenheim Committee on elementary and secondary aeronautical education and the Aeronautical Chamber of Commerce of America are planning to furnish information gathered from the aeronautical industries that should be of value in establishing public-school aeronautical courses.

Training of Automotive Mechanics

Automotive training in the City of Detroit is given in two types of schools, technical and trade schools. In the technical school the work is divided into six divisions, each division being a distinct unit. These units are: (1) Machine fitting, (2) internal-combustion engines and chassis, (3) automotive electricity, (4) welding, (5) automobile repair, and (6) engine testing.

Machine fitting consists of hand-tool work almost entirely. The object of the course is to give skill in the use of such tools as hammers, chisels, files, taps, dies, reamers, drills, micrometers, scrapers, and other hand tools. Internal-combustion-engine work consists of engine theory and study of internal-combustion-engine construction for all types of automotive engines.

Automotive electricity consists of a technical study of direct-current electricity, induction, capacity, resistance, electrical circuits, and magnetism. A thorough study is made of the general circuits on popular automotive vehicles, with a small amount of practical experience in operating and testing these units. The evening-school course is attended largely by auto mechanics who wish a more technical training concerning automotive electrical systems.

The welding work consists of acetylene and arc welding of steel and some practice on aluminum and cast iron and brazing. The demand for welding training far exceeds the capacity of the school welding shops. This is largely due to the increasing demand for welders in all phases of production and service work.

Automobile repair consists of automobile service work on popular cars that are taken into the school shops for repairs. The time spent in this course does not permit of a very thorough training in service work, but stresses fundamentals of service operations and trouble shooting.

Engine testing consists of simple engine tests to determine the horsepower, torque, brake mean effective pressure, and thermal efficiency of popular automobile engines. The purpose of the course is to familiarize the student with the characteristic tests for engines and to recognize typical engine performance. Naturally the student learns a great deal of the finer adjustments of engines and carburetors because it is necessary that everything function well if good results appear on the curve sheets.

The standard procedure for engine testing of the Society of Automotive Engineers is followed throughout this course. All of the foregoing courses are duplicated in both the day- and evening-school classes.

The technical high-school boys study in addition to the automotive courses the following: Five semesters of English, five semesters of mathematics, two semesters of history, two semesters of chemistry, two semesters of physics, two semesters of metallurgy, and five semesters of mechanical drawing. This training is not specifically for service mechanics, but many of the graduates enter service work as well as experimental work and other jobs requiring a technical training.

The automobile service course given in the trade school in Detroit is on the cooperative basis. The boys are placed as apprentices in service stations and spend two weeks in the shop and two weeks in school. The school training consists of garage practice, technology, service management, mechanical drawing, mathematics, and English. Garage practice consists of service work on popular cars, including complete overhauls of all major units and refinishing.

Technology consists of fundamental theory of engines, electrical systems, carburetors, fuel systems, chassis units, history of the development of the automobile, and an analysis of personal attributes for successful auto-service work.

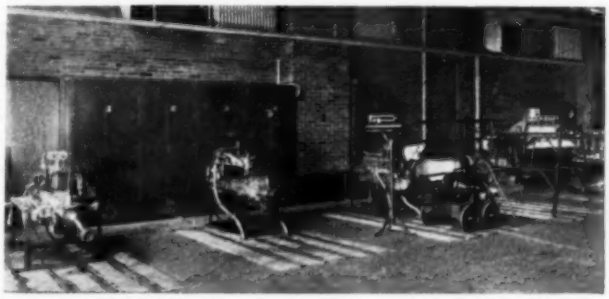


Fig. 4 Section of Automobile-Engine Testing Laboratory in Cass Technical High School

(The dynamometer and the engine-bed arrangement with underground exhaust system, are shown.)

Service management considers the problems of organization of the successful service station and studies the problems of equipment, records, overhead, personnel, and costs.

Mechanical drawing considers the usual assembly and detail drawings necessary for a complete understanding of and ability to read machine drawings. Mathematics deals entirely with shop problems and begins with fractions, decimals, and measurement.

English work in this school is almost entirely spoken, and the aim is to develop in the boy the ability to meet people and express himself clearly concerning shop matters. The Detroit public-school system maintains a placement bureau through which the industries are able to make contact with the individuals who have received the training that their work demands.

To sum up the training for automotive and aeronautical service work offered in the Detroit public schools, it may be said that the policy is to offer any courses for which there is a reasonable demand and to cooperate with the employing industries in every possible way.

MAN-52-4

Suggestions for Encouraging Education and Training for Industry

By HAROLD S. FALK,[1] MILWAUKEE, WIS.

Training of artisans and mechanics for American industry has been very much neglected in past years, and the movement for the revival of apprenticeship and industrial training can justly expect support. One of the great problems of apprenticeship and industrial training is to give the movement greater publicity, and to bring the subject before manufacturers and business men.

Local branches of the Society can effectively promote the movement by holding contests of various kinds related to industrial training. Because of the interest of engineers in drafting work, a contest in skill for drafting apprentices is suggested.

Such a contest may be conducted by a local committee, and if given extensive publicity will be very effective. Another possibility for the local branches is to give an award for the best paper written by an engineer on an assigned subject in the field of industrial training. The successful papers might be read before meetings of local branches of the Society. Also local branches might award a medal or cup every year to the corporations in their respective communities which have made the greatest advance in industrial training in a given year. Such a contest might be the most effective of all, but would need to be more carefully directed than the others.

Contests of this kind could be carried on without extensive study or research, and experience in similar contests conducted under other auspices has proved that they are very effective for purposes of publicity. Through contests the influence of the Society would force attention to the problems of industrial training on those who are most directly concerned.

IN SPITE of many notable exceptions, engineers as a rule give little thought to the young men who are growing up in industry and learning industrial work. Of course, it is fashionable to patronize a young engineer and help him over his early strenuous years, but such patronage is something quite different from an understanding of the need of American industry as a whole for trained young men, and young engineers are quite different from the type of young man with whom we are now concerned, that is, young men who do not graduate from a technical college, but who hope to become mechanics, technicians, draftsmen, or highly trained, highly skilled experts of any kind. A good example of this attitude is the case of a well-known engineer who recently made the statement that efforts in behalf of industrial training were a waste of time and energy. He said there was no need for all this activity because mechanics and skilled men of all kinds should be hired in the open market. He had never thought about the problem long enough to reach the conclusion that if there are mechanics in the open market somebody must have trained them.

However, it is no longer possible to hire skilled mechanics at will. In February, 1927, when business was rather dull and 40,000 men were reported to be idle in Milwaukee, a prominent oil-engine manufacturer received a considerable order, and wanted to engage 65 high-grade mechanics. Among all those unemployed men, it was impossible to find the 65 mechanics or anywhere near that many. The employment manager of the corporation visited other cities for a period of several weeks in a search for skilled men, but failed to assemble the required number. A certain foundry managed to get a little business in 1924, which was also a year of business depression, and was unable to engage 18 first-rate foundrymen, although the number of unemployed in the city at the time was as great as it had ever been. Our industries are very clearly confronted with the responsibility for training their own mechanics and experts.

Probably the majority of mechanics are foreign-born and foreign-trained men. American industries have been depending upon European apprenticeship systems for training, and the new immigration laws have cut off this source of supply.

Industrial Training a Proper Function of the Society

At first sight, this may not appear to be a problem of the engineering profession. However, the welfare of the profession depends upon the progress of industry, and to this extent, at least, engineers are concerned with these problems of industrial training. Moreover, the constitution of the Society specifies that two of its purposes are to broaden the usefulness of the engineering profession and to advance the standards of engineering. Both of these purposes may be accomplished in part through increasing the effectiveness of manufacturing industries by a higher development of skill on the part of those who work in these industries. The very existence of the Committee on Education and Training for the Industries is proof that industrial training of this kind is a proper function of the Society. The influence of the Society in industry is tremendous, and energetic promotion of industrial training by the Society will probably do more to develop the movement than can be accomplished in any other way.

Although much has been done in apprenticeship in various centers and individual industries, a mere beginning has been made, and very few manufacturers, comparatively speaking, have given the question much attention. Accordingly, it is suggested that the Society could probably do the most good by giving the industrial training movement the widest possible publicity.

The question will be asked, just how can the Society give wider publicity to this movement? It can be done in many ways; for instance, by contests of various kinds. Human nature seems to crave competition and striving. Throughout the history of mankind, contests have been held and prizes awarded, not only in athletics, but in almost every branch of activity. Would it not be well to take advantage of this human trait for the promotion of industrial training? Since it is important to bring the subject of industrial training before manufacturers in all parts of the country, local branches of the Society might well hold contests in their respective communities.

Contests in Skill and Workmanship for Drafting Apprentices

The draftsman gives the first concrete existence to the engi-

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Presented at the Annual Meeting, New York, N. Y., Dec. 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

neer's ideas, and certainly works closer to the engineer than any other tradesman. For this reason engineers are probably more interested in drafting work and draftsmen than in any other trade or tradesmen. Accordingly, a contest for drafting apprentices conducted by the local branches of the Society is suggested and this contest might well take the form of a competition in skill and workmanship.

A committee of engineers can be placed in charge, and experience has proved that the duties of such a committee would by no means be arduous, and moreover the work would be intensely interesting. The first task of such a committee is to become familiar with the type of contestants. College graduates should be excluded from the contest, which should be restricted to regularly indentured apprentices, that is, apprentices who are following a formal course of work for training in compliance with a definite agreement in writing. Since the Society seeks the promotion of organized training in industry, nothing can be gained by holding contests for any and all young men who happen to be working in a drafting room with the idea in mind of advancing themselves, nor should such young men be admitted to compete with those who are following a formal course. In other words, the Society should not encourage haphazard, slipshod methods of training draftsmen. A few hours in a number of drafting rooms spent in conversation with various apprentices will undoubtedly make the members of the committee sufficiently familiar with the type of men who are to participate in the contest. The purpose of this acquaintance with the young men concerned is to learn their capacity and to plan a contest which shall be appropriate.

The committee can select the problem or problems for the contest. These may be work in actual drawing or design, or the solution of problems in applied mathematics or science, or a combination of both. The design problem may well be a simple assignment such as drawing an ordinary pedestal bearing, given the shaft size and revolutions, or a flanged-faced coupling, given shaft size, revolutions, horsepower, and any other data which may be necessary. Because participation in such a contest will involve interruption of regular work, it would be well to limit the contest problems to a single day's work. The success of such a contest will depend upon the support of local manufacturers, and care must be taken not to antagonize them in any way.

It will be necessary to determine how many will participate, whether one shall come from each plant, whether representatives may be sent in proportion to the total employment of drafting apprentices or whether all drafting apprentices in the community may compete. A number of other details must be worked out such as a place in which to hold the contest, a system of identification so that the judges shall not know the names of those who participate, supervision of the contest, announcement to employers, provision of material and equipment, and other matters.

Before the contest is completed the committee will need to establish standards for the judgment of the work. Such standards would include proper design, dimensions, neatness and arrangement, sufficiency of views and similar points for the actual drawing, and correct solutions and evaluations of each problem in mathematics or applied science. The judges should be selected and instructed carefully, and the board of judges should include a number of engineers who are not members of the contest committee. Obviously the person who arranges the details, and to whom the contestants' identification numbers are known, may not be a member of the board of judges.

Extensive Publicity Is Necessary

In view of the purpose of the contest, the names of the successful contestant, or contestants in case more than one prize is available, should be given the widest possible publicity, and the prize or prizes should be awarded with much ceremony, preferably in the presence of as large and distinguished a gathering as can be assembled for the purpose.

Of course, a trade contest for drafting apprentices is merely one possibility. Such a contest cannot be carried out in most manufacturing localities for the reason that drafting apprenticeships are still somewhat unusual and there are but few communities in which they have been established. It might be advantageous to hold similar contests for apprentices in other trades. However, other contests, not of a trade nature, may easily be held and will prove to be of great benefit.

Annual Prizes for Papers on Industrial-Training Subjects by Engineers

Local branches of the Society may offer an annual prize for papers written by the members on some phase of apprenticeship. Such a contest might possibly be still more effective than a trade contest for the reason that a considerable number of engineers would be required to devote much thought to the subject of apprentice training, and their studies would force them to reach important conclusions which they would not otherwise attain. The contest would thus have the very much desired effect of calling the attention of engineers to the questions of trade training for young men.

It might be well to rotate the contest year by year through various classes of membership. In one year, the contest might be held for full members, in another year for junior members, in another year for undergraduate members, and after sufficient interest has been aroused, it might be interesting to hold a contest for members who are themselves the heads of business organizations. Subjects suggested for such contests are:

1 Why apprenticeship concerns the mechanical engineer
2 The need for apprenticeship in American mechanical industries
3 How apprentices may be effectively trained in this community
4 American young men and industrial work
5 Highly skilled men are still required in our industries.

A committee can handle such a contest very much as was suggested for the drafting contest. A number of details need to be worked out, such as to determine who is eligible for the contest and how eligibility is to be determined, the time limit for writing the papers and the length of the papers, a system for identification, publicity, the form of the manuscript, and other points.

A board of judges must be selected carefully, and the prizes should be awarded with much ceremony at some important gathering. It might be desirable to have the prize winners read their papers at such a meeting and permit those present to discuss them. Possibly, the best papers written in these contests could be included in a program for a meeting of the American Society of Mechanical Engineers and published in Mechanical Engineering.

Award to Local Corporation Which Has Made the Greatest Progress in Industrial Training

Still more effective would be the awarding of a cup or medal by the local branches of the Society to the corporation in the community which has done the most effective work or has made the greatest progress in the training of apprentices in the course of a year. Such a contest would have the distinct advantage that the competitors would be those who can do the most in the development of apprentice training. Regardless of promotion by various agencies, the fact remains that it is the employers who must actually engage apprentices and train them.

For such a contest it will be necessary to set up very carefully a schedule of points or standards for the selection of the winners and to evaluate these points as correctly as possible. The following are a number of points or standards which might well be included in the judgment:

1 Extent of organization of training courses, including the completeness of work schedules
2 Extent of training in the organization, that is, whether established in one or two departments or in all of them
3 Proportion of indentured apprentices who have graduated in a given period
4 Methods of shop instruction
5 Methods of school instruction
6 Methods and extent of general supervision
7 Number of apprentices in proportion to skilled mechanics.

Because the identity of the contestants cannot be hidden, a considerable number of judges need to be engaged, and they must act independently and report their findings on a suitable form on which the points or standards are included and assigned their corresponding evaluation.

The contest can be announced in advance by inviting corporations to participate, whereupon the competition would be limited to those who have entered, or the committee in charge and the judges can make from some reliable source a list of corporations who are entitled to participate and can visit them for the purpose of studying their work.

The success of such a contest, as of the others suggested, will depend almost entirely upon full publicity both before and after the contest, in newspapers, trade and technical papers and magazines, and in private publications of the various corporations which may have them.

Maximum Results From Minimum Effort

A distinct advantage of all these contests is that through them the Society can exert much influence without the heartbreaking labor of extensive research and study. Any one who has occasion or takes the trouble to read the reports of various technical committees of the Society can see between the lines a story of countless hours of painstaking investigation, countless additional hours spent in arranging and rearranging data and facts, followed by cautious progress toward conclusions, interrupted by frequent readjustment and much discarding. The committee work involved in contests would be much simpler. A few hours would be required to draw up the regulations for holding the contest, and these could be based very largely upon the regulations for existing contests of a similar nature already in force. A few more hours would be required by the committee for arranging the contest and the judges might be required to devote a day or two to their work. However, all the work would be comparatively simple, and ought to be enjoyed very much by those engaged in it.

If local contests of this kind are successful, there is no good reason why the Society should not sponsor national contests, in which case the local contests might be standardized and would serve as elimination contests for the national event.

Similar Contests Under Other Auspices Have Been Successful

Contests of this kind have been proved practical by experience. Successful competitions in the writing of papers have been conducted by a very great many agencies and institutions of different kinds. Some of these have been carried out on a national scale and have attracted much attention. The awarding of a prize to the corporation in the community which has made the greatest advances in industrial training for young men presents some difficulty so far as the correct selection of the prize winner is concerned. However, medals and awards are given annually by the Society under conditions equally difficult. The success of such a contest will depend very largely upon the prestige of the judges.

Trade contests present no great difficulty. For a number of years the Milwaukee branch of the National Metal Trades Association has conducted contests in trade skill for apprentices in machine work, drafting, pattern making, and iron and steel molding. These contests have been more and more successful in succeeding years. Successful nation-wide contests have been conducted by the American Foundrymen's Association during the last four or five years for apprentices in iron and steel molding and in pattern making. Elimination contests for apprentices in these trades are held by local foundry and manufacturing associations, and the final judgment of the castings and patterns, with the announcement and awarding of prizes, takes place at the annual convention of the association. The Milwaukee contests in pattern making and iron and steel molding have been preliminary to this national competition of the American Foundrymen's Association.

The popularity of contests of all kinds at the present time for purposes of advertising and publicity indicate that they are extremely effective for such purposes. Favorable results may be expected from the holding of contests by the Society of the kind suggested. The contests will attract general public attention and will make the chief officers of corporations, shop officials, technical engineers, and others appreciate the importance of organized training for young men who hope to work in the industrial field. Trade contests stimulate great interest and rivalry on the part of the apprentices themselves. But the most important advantage of all would be the prestige which organized industrial training would derive from the support of the Society. The standing of the Society is such that all manufacturers and all technical people are practically forced to take seriously any movement which the Society sponsors. It is extremely necessary at the present time that manufacturers and business men take the training of young men for industry much more seriously than they have in the past.

Discussion

Warren G. Findley.[2] The author has presented his project as a means of attacking a problem which faces American industry. The writer would like to call attention to the way the project can contribute to the solution of another problem, which, for want of a better name, he has called "the problem of the failure."

Each year every school is confronted with the question, "Whom shall we admit to the first-year class?" Various answers to this question are given in the various systems of admission used, but with one invariable result: some are selected; others are refused admission. These last have "failed." They feel they have failed. And that, from the psychological point of view, is equivalent to saying that they have failed. Letters, telephone calls, and personal visits ask, "Wherein did I fail?" and "What shall I do?"

Both questions require answers. It is impossible to waive all responsibility and say, "We offered you a chance and you failed to make the grade; that is the end of that." We say, "We regret to inform you that your test rating was too low to warrant your admission. You may try again next year." In a school which limits its enrolment it may be possible to soften this by stating that only a certain number can be admitted and the individual was refused because too many better prospects applied. This only disguises the real reason, for in such schools

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the limitation generally guarantees that theose selected are of satisfactory ability to make a go of the curriculum offered. To borrow a physical concept, a relatively static equilibrium exists between the abilities of the best 100 applicants of any year and the demands of the curriculum. However, regardless of how we break the news to him, our rejected candidate is a failure until we answer his second question with something more promising than permission to try again.

We should like to be able to say, "You do not show great promise of success with our engineering curriculum. We should suggest that you try this other kind of work." Some optimists in the field of vocational guidance feel that they can make such statements on the basis of certain aptitude tests. Such tests are still in the experimental stage as far as giving occupational guidance is concerned. However, if such a program as Mr. Falk has outlined were adopted, we could say, "You do not show great promise of success with our engineering curriculum. We should like to call your attention to a competition sponsored by The American Society of Mechanical Engineers in engineering drafting."

At this point we should be offering an alternative. We should no longer be leaving candidates worse, for their feeling of failure and inferiority, than we found them. It would certainly be a step forward over our present procedure if only a handful were to take advantage of this alternative. It now becomes a question as to whether we should be contributing significantly to the Society's program.

This last summer 1149 individuals took entrance examinations for the engineering courses at Cooper Union; 303 were admitted; 846, or approximately 74 per cent of them, were rejected, as described. What were those rejected men like?

By their appearing for examination, they indicated their interest in engineering. It may not have been an intelligent interest based on a thorough understanding of the nature of an engineering course. In the cases of a particular individual it may have been based on anything from hearing that engineering schools train men to build the impressive buildings and bridges seen every day to the applicant's having been pronounced a future Edison upon repairing a doorbell at an early age. The fact remains that a potential energy exists in the persons of 846 men who desire to become engineers.

When we reject these men, as we now do, this energy is gradually dissipated. The program before you offers an opportunity to harness some of this energy in a place where it is needed. If any of these men have the ability to acquire the skill called for, they should be better than average prospects.

The case for men rejected at entrance applies with the same force to men who flunk out. Selection of men for admission is meant to separate the sheep from the goats; in practice it becomes the matter of letting in as few goats as possible among the sheep. These few cannot do the work and consequently fail. And there are among these failures some who show a marked ability over the drawing board, while unable to carry the rest of the curriculum. These last fit the specifications of the contest exactly.

The author has offered one specific suggestion, a competition for drafting apprentices. He has gone beyond that and indicated ways of getting further suggestions through essays on industrial training by engineers and by a competition among industrial concerns for progress in industrial training. They who have the problem of admissions hope the plans prove feasible.

WILLIAM J. DONALD.[3] There can be little doubt about the need for the training of manual workers in American industry. Until the last few years America has been depending upon immigration for her supply of trained workers. Immigration restriction is undoubtedly cutting in on the new supply that we were accustomed to receive year by year. Actually, however, the curtailment of skilled immigrant workers has not been in proportion to the curtailment of the total number of immigrant workers, because skilled workers can more easily get within the quotas than unskilled workers.

This is a subject of complaint on the part of many European industrialists and also here in America, and their complaint is rather pointed, despite the conditions of unemployment abroad. No country and no industry is keen to lose its best workers.

The facts such as the author presents regarding the dearth of skilled workers could be amply supported by evidence from any other quarter. The attack on this problem may, of course, be made as the author suggests, by stimulating the interests of the apprentices themselves. One may well doubt, however, whether an approach to the apprentice himself would be nearly as effective as contests or other devices directed toward the executives and the industries themselves. It has become generally accepted that accident prevention becomes more effective when the efforts are concentrated on the foremen and other supervisors rather than on the multitude of manual workers.

Similarly, there is a distinct trend in industrial training toward concentrating on the ability and the responsibility of the foreman to train rather than directly on the apprentice himself. Training departments which undertake to do the whole training job can never more than skim the surface. A training program that contemplates the training of all supervisors to train their own workers, whether apprentices or those who have completed an apprentice course or semi-skilled or even unskilled workers, will achieve far more than the best training department can achieve alone.

Efforts to encourage education and training for industry will accomplish far more if the contests and awards are directed toward industry itself rather than toward the apprentices. Local contests which would recognize the training work of a particular company or companies would stimulate a degree of interest far in excess of contests which would recognize the skill of a few individual apprentices.

Essentially, training is a responsibility of management, and the solution of the problem of competent skilled workers will never be achieved as long as attention is directed only toward the workers.

The preparation of a schedule of points or standards for the selection of victors in corporate contests will no doubt arouse a great deal of dispute.

The author's schedule suggests four very interesting points, but there are other points which it seems will need attention as well. Some of them are as follows:

1 The extent of the effort to train supervisors to train
2 The proportion of supervisors who are coming under the influence of such a teacher-training program
3 The effectiveness of the formal set-up for training foremen to train.

There is a question, too, as to whether all of the attention should be concentrated on formally indentured apprentices. It is splendid to provide for a comprehensive period of apprenticeship that will carry younger workers through to the acquirement of a satisfactory degree of skill, but it is also important that semi-skilled workers should receive training. There is always a danger that a formal apprentice-training system for so-called indentured apprentices may direct attention away from the less formal training procedure for other workers.

[3] Managing Director, American Management Association, New York, N. Y. Assoc. A.S.M.E.

WILLIAM H. SNIFFEN.[4] The Chairman of Education for the Bridgeport Local Section of the A.S.M.E. says: "The contests referred to in the paper by Mr. Falk are undoubtedly a good method for furnishing an incentive to men working in the lines mentioned. This would be most applicable to industries where men are involved in a multiplicity of work of the same nature, and it would be a very good thing to have developed a plan for concerns that could take advantage of it."

The writer, long an executive in industry, and with experience in handling men, women, boys and girls, feels that it would be an inspiration and an incentive were any or all of the four points brought out in the preamble of the article put into effect. Too often there is an advance given to some one because of influence rather than to encourage those less fortunate and who have inert ability to perform what may appear as unusual.

The greatest element to success, and one that is often overlooked by the executives in industry, is the human element. This most important element to encourage the employee to produce quality as well as quantity is promoted through interest in the welfare of the employee in the plant and at home. The results attained are beyond the belief of some executives; yet with this contact and the other incentives set forth they will benefit employee, employer, and the public at large.

CHARLES F. BAILEY.[5] The author's suggestion for arousing interest in apprentice training should preferably be tried in the larger industrial cities and communities where there are groups of apprentices engaged in more or less similar work. In the smaller towns or cities where the industries are small and widely separated and the number of apprentices is small, the efforts required for success would be much greater owing to the lack of acquaintance and close contact. In such localities some other method might be more productive of stimulating interest.

The writer approves of the suggestion for an award for the best paper written by an engineer on an assigned subject, for the best drawing made by an apprentice, and for recognition of the corporation which has made the greatest advance in industrial training in a given year. He recommends the valuable aid provided by the Smith-Hughes Act designed to advance vocational training and education. Experience has proved this to be of great help and most satisfactory. At first it was feared that this might curtail the authority of the company with regard to the instructors, but such fears have not been realized.

In the art of shipbuilding many trades are involved, and apprentices are now enrolled in 19 or 20 different trades. In addition a number of other trades are being taught in which there is not sufficient training content to warrant an apprentice course. Under the Smith-Hughes Act foremanship training is also being carried on. At present the Dean of the Division of Economics at William and Mary College conducts a weekly round-table discussion on economics of foremanship, psychology, etc. There were 27 training instructors attending this course.

Under this apprentice training the boys are given the finest opportunity for individual progress. Some are carrying on, in addition to apprentice work and school class work, correspondence courses of study and doing, work assigned under direction of the supervisor. For these outside studies the boy is given additional credits. One apprentice whose home is in Pittsburgh, where he attended high school for about three years, came to Newport News to enter as an apprentice to learn shipbuilding. He has served two and one-half years in the yard, now is in the hull-drawing room, and in addition to his apprentice work and class work is taking college extension work in evening classes presented by William and Mary College.

In order to promote apprentice training it is first necessary to sell it to the company executives. This should be the aim of the Society, as it is the foundation required for success. A management in hearty, active sympathy with such training will foster it in many emphatic ways.

Next in importance is the personality of the apprentice supervisor. This should be outstanding, coupled with a human sympathy, liking, and admiration for the young men. Such supervisors and instructors are the only ones to be entrusted with this training.

Apprentice-training work when heartily fostered by the management and properly set up becomes more and more attractive and valuable to the company, to the apprentice, and to the community. Later it almost partakes of recreation for the sympathetic executive as he sees the brightest young men advancing from year to year and then becoming honored and trusted employees, foremen, supervisors, and superintendents. Outstanding examples include a superintendent of a large and important division in the works, a general foreman of the large shops covering machine work and engineering, a coppersmith foreman, electrical assistant foreman, and an engineer in charge of piping division. Half of the best draftsmen in this division are former apprentices. There are numerous outside examples of young men sailing at sea in ships reconditioned or built by the company, including the "Leviathan" and other important vessels driven by steam turbines, turbo-reduction gears, electrical propelling machinery, and Diesel engines. A city manager is a former apprentice.

If the training is made attractive and beneficial to the apprentices, there will probably be more applicants than can be accommodated. Such training should include classes for each apprentice, with two three-hour periods weekly, and these should be during working hours and on the company's time, the apprentices being paid for this work the same as for shopwork; the studies to include mathematics, physics, chemistry, laboratory work, English, economics, mechanical drawing, etc. These classes can be worked into very attractive periods. It is more and more important that applicants be selected from the better class of boys, with some high-school experience, if not graduates. Preliminary tests should be given, with a thorough physical examination and intelligence tests. It is realized that after spending four years in training only the brighter minds and best of bodies should be selected.

The mental attitude and morale must be constantly watched to keep interest and ambition, and care should be exercised as to the man with whom the apprentice works. This is one reason for selecting the training staff largely from former apprentices, chosen for their personality and moral tone.

The training course must be properly planned. By what is known as the block system the executive knows daily at a glance the exact standing of each individual. The block system can also be applied to the training of special-purpose men by taking different blocks and training in these only. Such training is often necessary in large shops where the skilled labor supply is curtailed.

In a large organization a boy after graduation is in danger of becoming lost to notice without the attention and the interest of a personnel superintendent.

All apprentices and the training staff are invited to a monthly foremen's lecture, where they see and hear the outstanding men in higher positions in the works.

In addition to instruction in classrooms and in the shops, the following outstanding points in apprentice training have a marked influence in building up morale and making the work successful and attractive:

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[5] Engineering Director, Newport News Shipbuilding and Dry Dock Company, Newport News, Va. Mem. A.S.M.E.

The adoption of self-government administered by an honor council.

Appointment of an athletic committee, the president of which is president of the apprentice association.

Organization of an apprentice band.

Apprentice Savings Association.

Public award of letters and honors earned.

In all training the application of the Richards Formula should be constantly in mind, wherein E = effective training, which involves and is proportional to $M + T + I + J + Mo$.

M	= manipulative skill	Shop		Hand
T	= technical knowledge	School		Head
I	= information (auxiliary)	School		Head
J	= judgment (trade)	School		Head
Mo	= morale	Sport		Heart

The Society can, if it will, promote and spread an active interest in the value of apprentice training, both to the worker and to the industry. It is encouraging to find a younger man like the author who has seen the importance of the movement and whose heart is in it. The influence and enthusiasm of a few men of this stamp will do much to promote a realization of the need of apprentice training throughout the country, and if this need is realized steps will be taken to meet it.

J. J. Morgan.[6] The author's plan seems to have been worked out carefully, and no doubt it will be found as successful in other large centers as it has been in Milwaukee. It seems desirable, therefore, that it should have been given the publicity and standing which will result from its presentation.

A description of work which is being done along this line in the gas industry by the Home Study Department of Columbia University may be of interest. In October, 1925, a course on manufactured gas was offered at the request of the Committee on Education of the American Gas Association. Instruction has been along practical lines in order to satisfy the requirements of men in the industry seeking further knowledge of gas company operation. It consists of 24 lessons covering the technical phases of the production, distribution, and utilization of manufactured gas, and treating also such allied subjects as safety, accounting, rates, the sale of gas, and public relations. The instruction assumes that the student has a high-school education or its equivalent and a knowledge of elementary chemistry and physics, but a majority of the men taking the course have had a college education.

Instruction is given by means of a text[7] written especially for the course and a syllabus giving (1) an outline of the subject matter, (2) the text and supplementary references, (3) a discussion of the subject matter and advice to aid in its study, (4) questions and problems for the student's notebook to lead him to definite conclusions, and (5) examination questions to test the student's mastery of the lesson. The examination papers are returned to the students with a letter explaining errors which have been made and offering suggestions as to the mastery of the subject matter.

[6] Associate Professor of Chemical Engineering, Columbia University, New York, N. Y.

[7] "Manufactured Gas, a Textbook of American Practice," by J. J. Morgan.

It is planned that each lesson should require 20 hours of actual work by the average student, but many students spend much more time than this.

The American Gas Association cooperates in the preparation and presentation of the course through an Advisory Committee of four leading gas engineers who review all the material for the course and act as general consultants in its conduction.

Since its beginning in 1925 some 1400 men have been enrolled in this course, of which number a few more than 400 have completed the work. It is probably the first home study or correspondence course given by a university in cooperation with the national association of a major industry.

Author's Closure

It is fortunate that Mr. Findley has pointed out the value of apprenticeship and industrial training for the great rank and file of young people for whom higher education is impossible for one reason or another. Apprentice training is really an attempt to apply in the field of industry those same principles of general opportunity which have made public education effective in the United States. Mr. Findley discusses applicants for college training who have failed to pass the entrance examination and suggests the possibility that these young men might enter the drafting field through a contest in drafting of the kind described. Perhaps it has not been explained clearly enough in the paper that these contests are intended only for apprentices who have been in training for some time. They would therefore not be open to beginners. It may well be that contests might be held as an entrance requirement for drafting apprenticeship, but we have had no experience in this direction, and while we admit the possibility of the plan, we are not in a position to endorse it.

Mr. Donald's remarks provide an opportunity to mention that experience in Milwaukee metal-trades plants indicates that the entire apprentice-training program, as well as the training of other workers, centers around foremen, department heads, and special instructors who may be appointed in various departments. The function of the training department is to direct the work and make all necessary arrangements, but the actual training, the actual imparting of trade knowledge and skill, must necessarily be done by those under whom the apprentices and workers are employed. In the paper the assumption was made that effective apprenticeship implies a qualified and trained corps of foremen and department heads. Perhaps this was taking too much for granted, and Mr. Donald's emphasis on the point is appreciated.

It has been the author's experience that contests for apprentices stimulate as much interest among foremen and department heads as they do among apprentices themselves. At the same time, competitions for employers and supervisory persons would also be very effective.

Mr. Bailey questions the advisability of holding competitions of the kind described in smaller communities or in communities with a large number of small industrial establishments, for the reason that sufficient coordination between these elements may not exist. This suggests the question, Would not the holding of a contest create the very cooperation which is needed for effective community apprentice training?

MAN-52-5

Management of Service Departments—Budgeting and Wage Incentives Applied to a Large Organization

By WILLIAM B. FERGUSON[1] and TOM H. BLAIR,[2] NEWPORT NEWS, VA.

The organization and the management of the service departments in a large plant with over 6000 employees doing a great variety of unstandardized work of fluctuating volume and spread over an area of 140 acres present many difficult and complicated problems in comparison with similar problems in the usual manufacturing establishment. After the productive or operative departments in the Newport News plant had been reorganized and modern methods of planning, scheduling, production control, cost control, and wage-incentive plans had been put into effect over a period of about five years, it then became possible to undertake further improvements in the staff and service departments with respect to better organization and the training of executives and employees, and the measuring in some way, directly or indirectly, of the value of the service rendered or the output of these service departments; and finally the applying of bonus plans or other wage-incentive schemes to reward the employees in these service departments, with over 700 men and women, for improved efficiency. The methods described are the result of preceding study and preliminary work for over a year and represent the simplest forms of wage incentive that seemed practicable to apply to a large plant of this character. The first service department was put on a bonus system in April, 1928, and there resulted a net saving during the first 15 months (that is, about four months after the last service department was put on a bonus system) of about $175,000 for the whole plant. The simple methods used have created great interest on the part of heads of departments and employees. The main feature is that an opportunity has been and can be offered to all employees in all service departments for increasing their earnings in proportion to their results and thereby increasing the net earnings of the company to a much greater degree than has probably ever been appreciated.

MANAGEMENT of service departments in any large plant, especially a very large plant such as will be described, and application of scientific methods of study and analysis and cost control are much more difficult than applying scientific management to ordinary manufacturing or productive departments where the work can in a measure be standardized. In productive or operative departments as distinguished from service departments, it usually is possible after thorough study and analysis, and after the education and training of executives, to put into effect, with the support and interest of all concerned, the best methods of modern management in proper sequence, beginning with drawings and material supply, material control and distribution, planning, scheduling, and routing, cost control and cost budgeting, and finally wage-incentive plans, either piecework or bonus or premium methods of payment based upon definite and measurable production or output. This last step, that of the fair application of wage incentives or some scheme of equitable reward to individuals or groups for services rendered, may be looked upon as the final stage or step in progressive management which insures a continuous and perpetual interest on the part of all employees in getting better production and increasing the prosperity of themselves and their employers. Therefore the practical development and application of fair rewards or wage incentives for the large number of men and women engaged in service departments is a forward step toward the mutual confidence and success of employees, management, and owners, and marks a new era in industrial management, because of this opportunity for reward being offered to those employees whose work cannot be definitely measured or standardized in the ordinary sense, who never before have had a real opportunity for increased earnings based upon their individual or group efforts and results.

Unusual Conditions for Service Departments to Meet

The plant selected for this discussion is the largest shipyard in America, the Newport News Shipbuilding and Dry Dock Company, on the James River in Virginia, employing at present about 6400 people, of whom about 1000 are employed in what will be called "service departments," which includes general office work, drafting work, accounting and cost departments, material supply, storage and transportation, time-study departments, and a great variety of other functions that are shown in the upper part of the chart, Fig. 1, which is a skeleton organization chart of departments whose heads report to the Production Manager or are coordinate with the heads of departments under the Production Manager. The operative departments are under four superintendents, shown in the lower half of the chart. There are about forty separate operative departments, having over 5000 employees, including practically every craft or trade that has to do with metalwork or woodwork. The plant has its own foundries making iron, steel, and brass castings. It also makes most of its own forgings. It therefore has smith shops and several machine shops. From the nature of its products and from its location the plant has to be practically self-contained; that is, it does practically all of its own work, including piping and sheet-metal work, coppersmith work, and all woodwork. In the woodwork departments alone there are about 700 employees. Since the principal business of this company is building and repairing ships, the greater part of the force is at work in the open or outside of the sheltered shops, either on the ways, in the dry docks, or at the outfitting piers. In addition to building and repairing ships the plant is also engaged in hydraulic work, making water wheels and hydraulic accessories as well as hydraulic structural work such as flood gates and trash rakes. The plant also does an extensive miscellaneous jobbing business, especially in forgings and

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Contributed by the Management Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

castings of various kinds. The character of the work itself requires that the shops and other facilities extend over an area of about 140 acres, which gives rise to many unusual problems in plant engineering, transportation, storage of materials, and materials handling methods. (See Fig. 2.)

Practically none of the work in the plant is duplicate work, and therefore by its very nature it cannot be standardized nor can repetition methods be used as in ordinary manufacturing. The situation with respect to the management of service departments in particular is complicated by all these conditions and also by the fact that practically all work is contract work (that is, no work can be manufactured for stock) and by the further important fact that the ship-repair business is somewhat of a seasonal business, with a large rush of work at various times and at other times this work being slack. This gives rise to somewhat violent fluctuations in the volume of work and the total number of employees, which of course affects the cost of the service departments and makes it difficult to fix a budget for departmental cost. During the last two years the force has been as low as 4400 employees and as high as 6600.

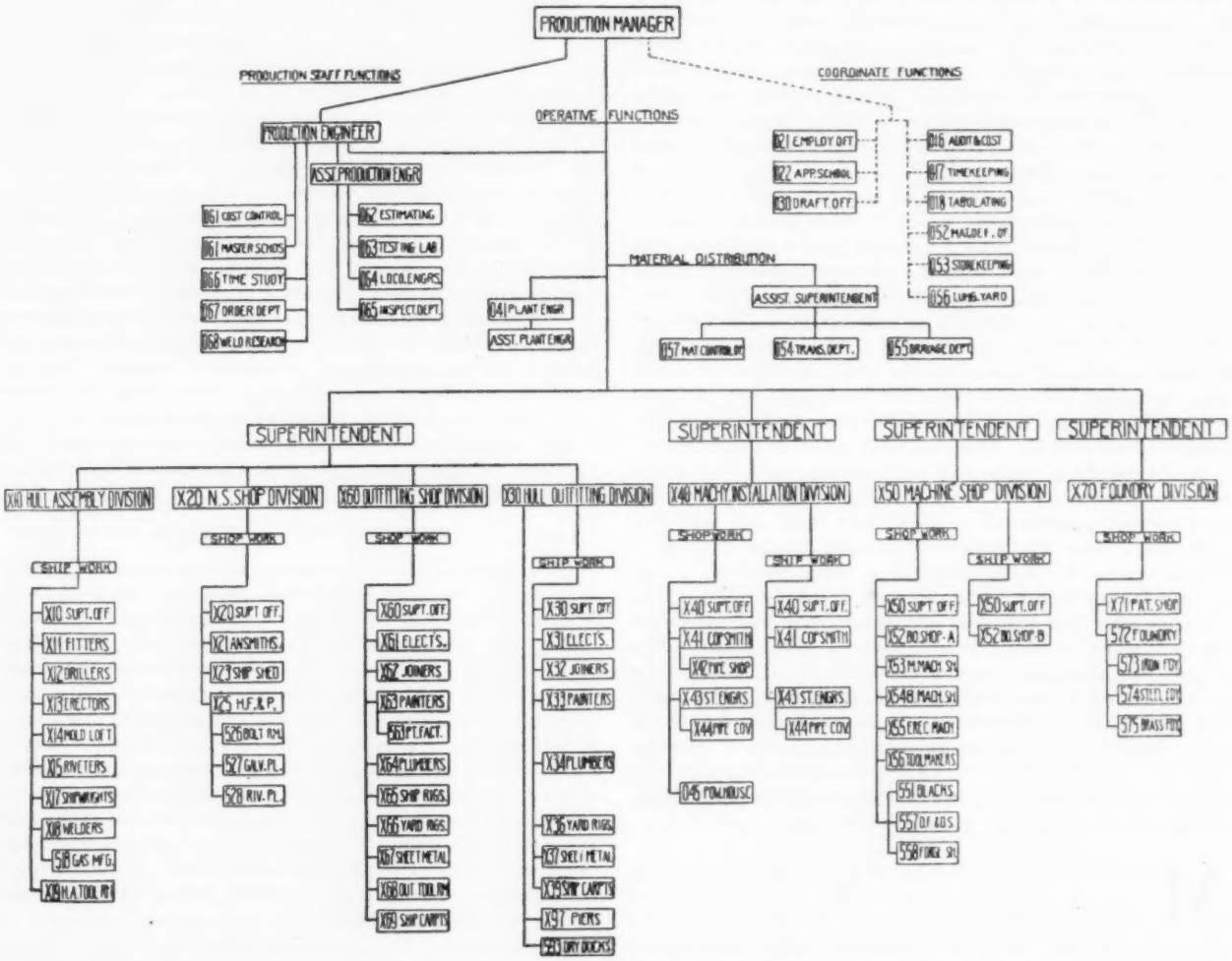


FIG. 1 ORGANIZATION OF PRODUCTION FUNCTIONS, SHOWING SHIP WORK AND SHOP WORK SEPARATELY

Group bonuses can be applied to the work of service departments where one cannot measure separately the output of individuals on account of the great variety of functions performed by nearly every person in these departments. This condition in this large plant becomes apparent from a study of the functions when given in detail, as set forth in the "Supervisors' Manual," extracts from which are given in Appendix No. 1, covering briefly the main functions of the Production Division (under the Production Engineer, 88 employees on bonus plan), Time-Study Department (34 employees), Order Department (18 employees), Employment Manager (10 employees), Plant Engineer (25 employees), and Inspection Department (under Production Engineer).

The foregoing variable and uncertain factors make it necessary to establish, by study of previous cost records of service departments, some kind of budget or bogey for the overall cost or output of these departments in quite a different manner from that in which it can be established for ordinary manufacturing plants making a uniform product of either standard or predetermined volume. The first thing, therefore, to be described will be the method of setting budgets or bogeys for the 23 service departments, all of which are now on some incentive system, based upon these budgets. Each budget has been developed in the form of charts or curves based upon the fluctuation in the working forces or in the amount of service required by each service department.

INCENTIVES AND BUDGETING

TRANSPORTATION SERVICE AND MATERIALS HANDLING

To illustrate exactly how this has been done, there first will be

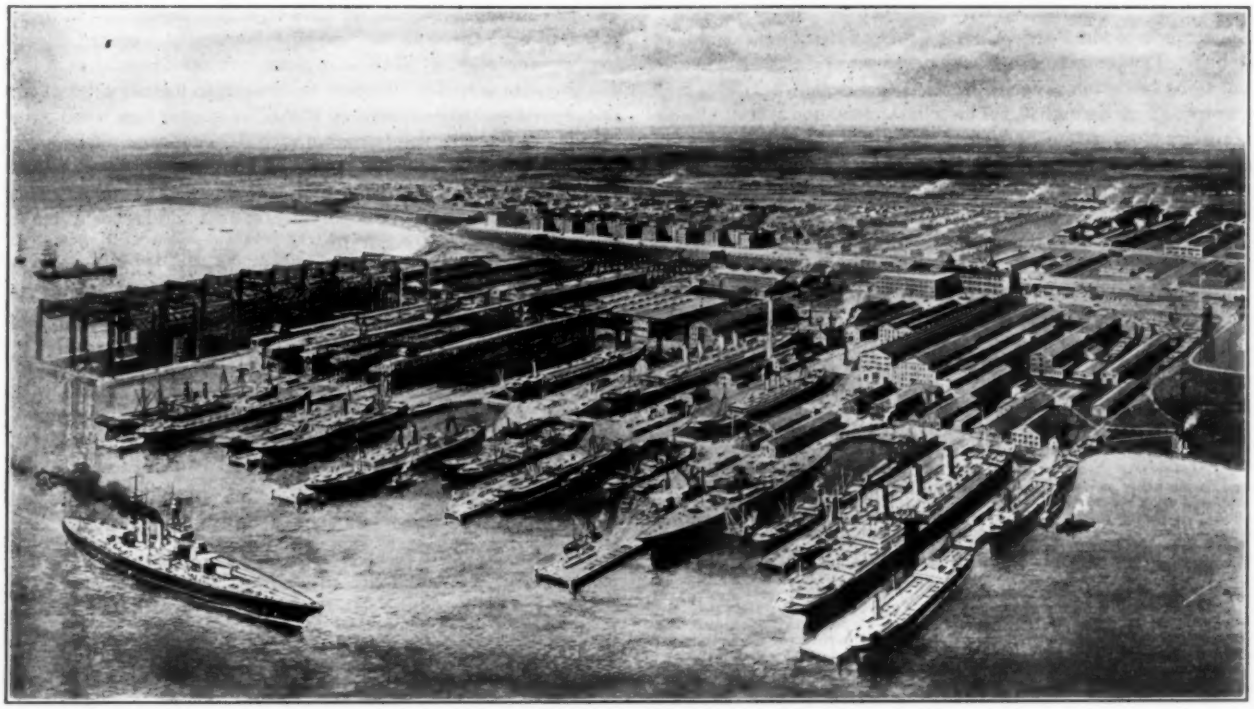


FIG. 2 VIEW OF NEWPORT NEWS SHIPBUILDING AND DRY DOCK COMPANY'S PLANT

selected one of the most difficult departments to manage economically, the Transportation Department, whose general duties are given under 16 main headings, as follows:

1 Render switching service, i.e., shift cars from interchange to unloading points in the yard and returning same to interchange when empty. Shifting all cars from one location to another in yard. Transporting all materials too heavy to be handled by trucks and trailers
2 Furnish crane service for handling materials that are not in reach of stationary gantry cranes
3 Load and unload foreign cars out of radius of stationary or gantry cranes. Furnish hand labor for loading and unloading cars, except where labor is furnished by other departments
4 Hostle all locomotives and locomotive cranes
5 Make minor repairs to cranes, locomotives, and flat cars
6 Inspection of foreign cars on receipt and release, repairing any minor damage done to same while in yard
7 Record and report fuel deliveries made to various places in yard
8 Furnish labor to work in dry docks to assist yard riggers in emergencies
9 Furnish steam for ships, such as steaming tanks, condensers, heating boilers, and heating ship
10 Yard cleaning in certain zones
11 Yard grading
12 Maintenance of yard tracks, lawns, surface drains, and retaining walls
13 Salvaging, classifying, and loading for shipment all yard-scrapped material
14 Supply foundry with requirements of scrap
15 Bagging coal sold to employees
16 Record and report deliveries to interchange.

The number of employees engaged in the foregoing services has varied from 150 to 75 during the last four years.

As will be seen from the foregoing duties or functions, the Transportation Department is a real service department. To perform this service, it has the following equipment:

5 locomotives, various types
16 locomotive cranes, 10 to 125 tons capacity
78 flat cars, 8 different types
25 miscellaneous cars, 9 different types.

There are approximately 14 miles of railroad track in the plant.

CHANGE FROM PIECE WORK TO BONUS PLAN

Although certain classes of work in this department had been placed previously on an incentive basis by the establishment of standard piece-work pieces wherever possible and subcontracts for certain other jobs where practicable, yet at no time was it possible to have the efforts of more than 35 per cent of the department's personnel influenced by some kind of a wage-incentive plan. While such work as unloading coal, coke, pig iron, foundry sand, steel plates, and other general work which lends itself to an exact quantitative or physical measurement of unit output could readily be done by piece work, there remained a much larger part of the department's regularly performed duties that could not be included in any kind of piece work, bonus, or subcontract arrangement; for example, the best locomotive-crane operators, who were never assigned to the simpler work of unloading coke, pig iron, or sand, but were necessarily always used on jobs requiring greater experience and skill, such as servicing ships in dry dock and other work of a generally unmeasurable nature.

Apart from the strictly productive labor in the Department whose maximum output could not be encouraged by any of the usual forms of wage incentive, there remained the entire supervisory force none of whom had an opportunity for increasing their earnings by increasing their efficiency though exercising at a near maximum.

The plan which was finally evolved for this first department of the general and service group and which was intended to place the entire department on a measured cost-efficiency basis is described in detail below.

As the basis on which the group plan was designed was one of increasing cost efficiency, an "expense-budget normal" was first set up after a careful study of past costs in this department as compared with the total yard direct payroll for equal periods. In order not to handicap the participating group at the outset, the budget normal upon which the bonus plan was based did not

exact any immediate betterment in costs over past performance before the zero or starting point of bonus earnings could be reached. The budget normal which was set up as a performance level to be beaten in order to pay a bonus is shown in Fig. 3 as expense-budget normal *A*. This chart also shows very clearly the results obtained in the way of cost improvements in this department since inaugurating the group plan.

Details of Bonus Plan

The following joint memorandum authorizing the installation of the group bonus plan was issued to those concerned by the Time-Study Engineer, Foremen of Transportation Department, and Assistant Superintendent of Material Control, covering the details of the Bonus Plan:

AUTHORIZATION INSTALLATION OF BONUS PLAN

Joint Memorandum, March 1, 1928

Newport News Shipbuilding and Dry Dock Company

Transportation Department—054

Subject.—Bonus plan for employees of the Transportation Department based on monthly savings made between cost and the expense budget.

Budget.—The monthly budget used in the bonus plan will consist of a standby charge of $5000 plus 2.34 per cent of grand total direct labor for the yard. To this will be added an amount equal to all expense in account 4.

Cost.—Cost in this department to be compared with the above budget will consist of all expenditures under expense accounts 1 to 9, inclusive, as shown in the Blue Cost Book, all departmental cost or labor charged directly against a particular contract or order number, all plant service charges, and all departmental bonus payments which will be charged to 0544–4.

Plan.—All employees of the Transportation Department, including the foreman, are to share in 50 per cent of the total savings of departmental budget from month to month based on a rolling average of six months.

Bonus Division.—The department shall be divided into the four following classes for the purpose of proper bonus divisions: Class 1, foreman; class 2, chief dispatcher; class 3, dispatcher and clerk; class 4, all other employees. Each class shall receive a certain percentage of the bonus to be divided, and this percentage will be governed by average number of men in department from month to month. Classes having more than one man will have respective bonus divided pro rata among the men of that class according to hourly rate and number of hours worked during the month.

Bonus Distribution by Per Cent Among Classes.—

Total number of men in department, inclusive	Classes 1	2	3	4
86 to 95	3.3	2.2	2.0	92.5
96 to 105	3.0	2.0	1.8	93.2
106 to 115	2.7	1.8	1.6	93.9
116 to 125	2.4	1.6	1.4	94.6
Over 125	2.1	1.4	1.2	95.3

Notes.—In case material changes are made in the organization of the work from time to time (other than variations in number of employees), the percentage of bonus division for the several classes will be equitably adjusted to suit the new conditions. Any bonus systems of piece-work prices now in operation will become void the date this plan goes into effect. It is proposed to put this plan in effect March 1, 1928, and it will be subject to revision January 1, 1929.

(Signed).....
Foreman Transportation Department

(Signed).....
Time-Study Engineer

(Signed).....
Asst. Supt. Material Control

Determining Basis for Bonuses

In setting up a bonus plan of this type it has been found that there are certain steps to be followed. First, the functions of the department are to be analyzed with the idea of determining where service is rendered and how it is to be gaged. The plan usually embraces the whole department, but may be used for certain groups of persons in one or more departments. In the case of whole departments, service is usually rendered either to the whole plant or to certain other departments. The amount of service to be required is determined by the number of persons to be served or the pay of these persons. For some plans there is used the total payroll of the departments served and for other plans the total direct-labor payroll, depending on the type of service required of the department to be placed on bonus. Some departments serve not only the productive or direct labor of other departments, but the indirect labor as well, while in other departments service is rendered only the productive labor.

After deciding where and how service is rendered and how it shall be gaged, the next step is getting the figures, which are to be in two groups, the gross budget figures and the cost figures. The gross budget figures are those on which the budget is to be based and are those already explained—namely, number of persons served, total pay of those persons, or total direct labor of the departments served. The cost figures are to include all costs of the department to be placed on bonus, no matter how these costs are incurred, exclusive of direct material.

These figures are to be taken by months over a period of time extending from peak to slump, or vice versa, if possible. This gives the two extremes in departmental cost and serves to make the budget plan more accurate.

A graph is then plotted with the cost figures, and those from which the budget is to be set, parallel to each other so as to show the amount of divergence between the two extremes, high and

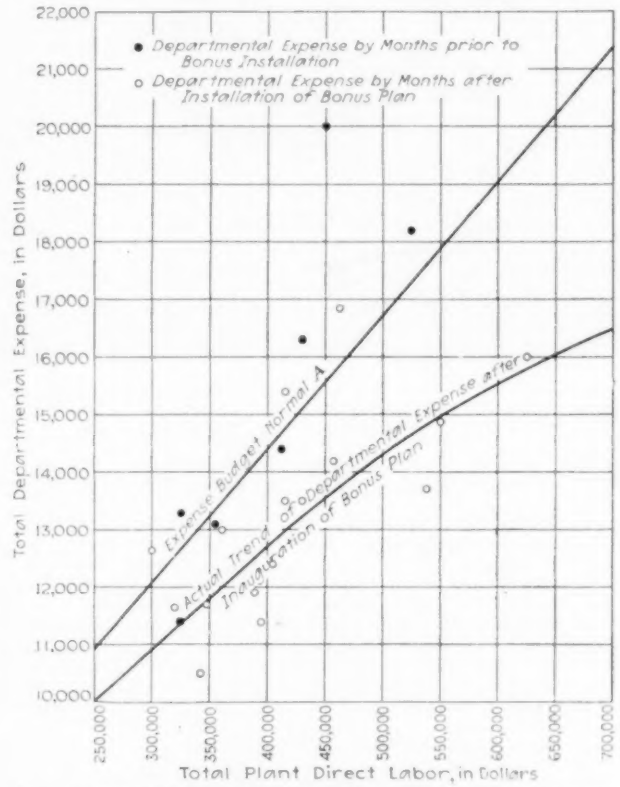


Fig. 3 Chart Showing Effect of Group Bonus Plan on Costs of Transportation Department

low. In arriving at a budget there is first set a constant, or standby, figure. This is supposed to be the cost of the department at a mythical zero of work in the plant. The larger the constant figure, the smaller the amount of fluctuation in the budget, and vice versa. However, this constant should in no case be larger than 75 per cent of the department's smallest monthly costs. Next there is the item of special allowances to be taken care of. In the plant under discussion the departments have very little to say as to the amount of money to be spent in repairs to the buildings used by them, this being taken care of by the Plant Engineer, so an allowance is made to take care of account 4, which is repairs to buildings and structures (and a part of the departmental expense). Other special and periodic charges are to be taken care of by allowances.

In setting the budget the cost figures are used for the six months immediately preceding the installation of the bonus plan. There is subtracted from the total six months' cost the standby charge for the same period and the total of the items for which allowance is to be made. This gives what might be

termed "net cost." Then the percentage of net cost to gross budget figures for the same period is determined. This gives the standby, plus allowances, plus a percentage of the gross budget, which is to be the departmental budget. If the divergence between cost and the gross budget as plotted on the graph is too great, it can be taken care of by following the foregoing procedure for the six months at the peak (or slump) and plotting the results on a graph. Connecting these two points by a straight line gives the intermediate budget.

The final written plan should not only give in concise form the foregoing results, but should also state which employees are to participate in the bonus and to what extent they participate. It is well to include in the plan a statement as to the quality of service rendered not being impaired or the plan is void. This is for the purpose of preventing a reduction of cost by lowering the standard of the service. This is passed on by a committee when necessary.

Finally, the plan carries a date when it is to become subject to revision. The revision dates are usually January 1 and July 1. The plan is practically guaranteed until then.

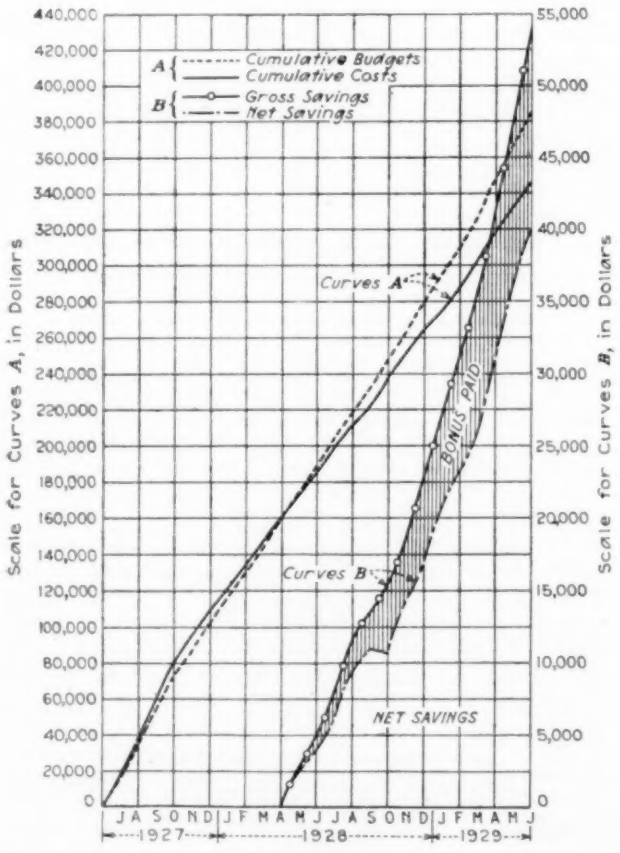


Fig. 4 Effect of Group Bonus Plan on Costs of Transportation Department

After the plan is written it is agreed to by the responsible head of the department and by the head of the Time-Study Department, who is responsible to the management for formulating and operating the various plans.

Cost Results From Bonus Plans

Fig. 4 shows graphically the effect of the Transportation Department's group bonus plan, as described, on the operating costs of that department. In the same way Fig. 5 indicates the results obtained in all of the general and service departments now working under similar group-participating bonus plans.

The plan is set up on a six months' rolling average; that is, it was started with six months' cost and six months' total yard direct payroll, and as a month is added a month is dropped—when April, 1929, is added October, 1928, is dropped.

Table 1 shows the form used for bonus computations for the

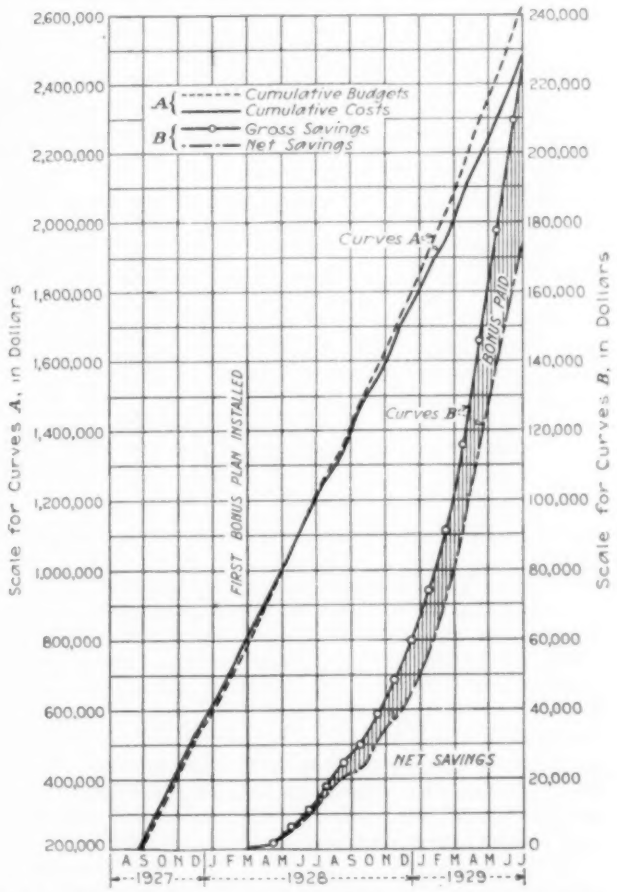


Fig. 5 Effect of Group Bonus Plan on Costs of General and Service Departments

Transportation Department. Similar records are kept for all service departments.

As stated elsewhere, in the bonus plan the savings shown between the budget and cost are split evenly; one-half of the savings is paid to the men in the department, as outlined in the bonus plan, and the other half goes to the company. At the end of a month, when the bonus is paid, the amount paid is charged into the next month's cost for the department, so that in the course of time it figures out less than an even division, as shown in Figs. 4 and 5.

All of the costs of the department are kept; that is, the total payroll plus all charges for repairs to equipment, coal, oil, waste, office supplies, etc. As will be seen, this gives every one a chance to effect a saving all down the line, not only in the number of men on the job and the length of time on each job, but also in the quantity of coal consumed and other features. This coal is quite an item with the present equipment.

The biggest factor in getting this plan over is "selling" it to the men in the department. This takes a lot of time and salesmanship, and for the first two departments there was put on this plan one man who lived right with them for the first two months,

and it was his job to suggest every saving possible to the foreman. Naturally the first people to see the benefit of the plan are the supervisors, and once they are convinced, the conversion of the others is easy.

As is seen from Table 2, a slight decrease in the percentage of men in this department as against the total yard direct-labor force was shown in 1926. In January, 1927, a new supervisor was put in charge of this department, and he made a further reduction. In March, 1928, the bonus plan was started and still further improvements were shown, and the end is not yet in sight.

The actual bonus paid the men in this department for the month of May, 1929, was about 21 per cent of their wages, which is the largest bonus paid to date.

All of the service departments are now working on some kind of an incentive system.

TABLE 1 BONUS COMPUTATIONS FOR TRANSPORTATION DEPARTMENT—054

Month	Weeks	Yard direct labor	2.34 per cent allowance	Account 4	Standby	Total budget	Accounts 1 to 8	Plant service	Direct labor	Total cost	Monthly savings	Six months' average	Bonus paid
1927													
July	4	$431227	$10091	$1049	$5000	$16140	$ 9428	$3990	$2908	$16326	$ 186[a]	....	....
August	5	523879	12259	949	5000	18208	12156	5606	2703	18223	15[a]	....	....
September	4	362367	8479	7892	5000	21371	16888	3677	1997	22562	1191[a]	....	....
October	5	448999	10507	1534	5000	17041	13647	4532	2181	20360	3319[a]	....	....
November	4	357201	8359	661	5000	14020	8156	2716	2304	13176	844	....	....
December	5	412069	9642	1219	5000	15861	8624	3109	2726	14459	1402	....	....
1928													
January	4	327381	7661	580	5000	13241	6311	2679	2439	11429	1812	....	....
February	4	323077	7560	2532	5000	15092	9116	2469	1706	13291	1801	....	....
March	4	298197	6977	663	5000	12640	7684	2781	2187	12652	12[a]	....	....
April	5	416954	9757	1226	5000	15982	8415	2998	4007	15420	562	....	....
May	4	348980	8166	1269	5000	14435	6445	2385	2878	11708	2727	$1362.00	$ 681.00
June	4	361192	8452	849	5000	14301	7377	2910	2713	13000	1301	1365.16	682.58
July	5	415797	9730	1174	5000	15904	8352	3131	2066	13549	2355	1455.66	727.83
August	4	343299	8033	656	5000	13689	6114	2404	1983	10501	3188	1686.83	843.41
September	4	319821	7484	734	5000	13218	7508	1493	2634	11635	1583	1952.67	976.33
October	5	462937	10832	738	5000	16570	10838	3399	2619	16856	286[a]	1811.33	905.66
November	4	388149	9082	1224	5000	15306	7158	2250	2505	11913	3393	1922.33	961.16
December	5	430402	10072	1128	5000	16200	8147	3234	2107	13488	2712	2157.50	1078.75
1929													
January	4	395847	9263	772	5000	15035	7030	2557	1796	11383	3652	2372.66	1186.83
February	4	406572	9514	616	5000	15130	7808	2311	2282	12401	2729	2297.16	1148.58
March	4	458188	10722	1056	5000	16778	9372	2452	2404	14228	2550	2458.33	1229.16
April	5	627239	14677	1469	5000	21146	10167	3193	2658	16018	5128	3360.66	1680.33
May	4	537992	12589	1167	5000	18756	8757	2720	2230	13707	5049	3636.66	1818.33
June	4	550095	12872	1091	5000	18963	9701	2899	2273	14873	4090	3866.33	1933.16
July	5												

[a] Deficit.

TABLE 2 AVERAGE NUMBER OF MEN IN ATTENDANCE IN YARD AND IN TRANSPORTATION DEPARTMENT

Year	Plant	Transportation Department	Percentage
1924	4228	127	3.0
1925	4664	141	3.0
1926	5400	142	2.6
1927	5256	110	2.1
1928	4403	84	1.9
1929 to end of May	5430	83	1.5

Storekeeping

Nearly every plant has a Storekeeping Department. The bonus plan in the Storekeeping Department was started in May, 1928. This plan was worked out from the number of men required in the storerooms to supply material to the mechanics and other production workers. As will be seen from Table 3, there were four years' figures to work from—1924, 1925, 1926, and 1927.

TABLE 3 AVERAGE NUMBER OF MEN IN ATTENDANCE IN PLANT AND IN STOREKEEPING DEPARTMENT

Year	Plant	Storekeeping Department	
1924	4228	91	1 storekeeper to every 46 employees
1925	4664	85	1 storekeeper to every 55 employees
1926	5400	104	1 storekeeper to every 52 employees
1927	5256	108	1 storekeeper to every 48 employees
1928	4403	74	1 storekeeper to every 59 employees
1929 up to June	5430	78	1 storekeeper to every 69 employees

A good comparison here is to take the year 1927, when there were no bonus plans in this department and there were 5256 employees in the whole plant and 108 men in the Storekeeping Department, or 1 storekeeper to every 48 employees. Compare this with 1929, when there were 5430 total employees, with 78 men in the Storekeeping Department, or 1 storekeeper to every 69 employees—a reduction of 30 men in the Storekeeping Department, with approximately the same number of employees in the yard.

The following is the bonus plan as adopted for this department:

STOREKEEPING DEPARTMENT BONUS PLAN

Joint Memorandum, May 28, 1928

NEWPORT NEWS SHIPBUILDING AND DRY DOCK COMPANY

Storekeeping Department—053

Subject.—Bonus plan for employees of the Storekeeping Department based on monthly savings between cost and the expense budget.

Budget.—For a four-week month the budget will consist of a standby charge of $2000, plus $1.72 for each man in attendance throughout the yard, and to this will be added an amount equal to all expense in account 4, repairs to buildings and structures. For a five-week month the budget will consist of $2000, plus $1.903 for each man in attendance throughout the year, and to this will be added an amount equal to all expense in account 4, repairs to buildings and structures.

Cost.—Cost in this department to be compared with the above budget will consist of all expenditures under expense accounts 1 to 8, inclusive, as shown in the Blue Cost Book. All departmental cost or labor charged against a particular contract or order number and all departmental bonus payments will be charged to 0532–4.

Plan.—(1) All employees of the Storekeeping Department, including the foreman, are to share in 50 per cent of the total savings under the budget from month to month, based on a rolling average of six months. (2) This is providing the service of the Storekeeping Department to the operating departments is not impaired. (3) The department budget and the provision in (2) as to the service to operating departments not being impaired will be determined jointly by a committee of three, composed of General Manager, Production Manager, and Production Engineer. This committee will also determine the amounts of bonuses earned.

Bonus Division.—Bonus paid each individual will be paid according to the total amount of money each individual receives as salary or wages during the month.

Notes.—In case material changes are made in the organization of the work from time to time (other than variations in number of employees), the plan will be equitably adjusted to suit the new conditions. Any bonus system or piece-work prices pertaining to or affecting the Storekeeping Department will automatically become void the date this plan takes effect.

Effective May 29, 1928; subject to revision, January 1, 1929.

(Approved) _____
Material Agent

(Approved) _____
Time Study Engineer

Since the first of this year up to May, inclusive, this plan has paid the employees of the Storekeeping Department a bonus as follows: January, 5.6 per cent; February, 5.2 per cent; March, 5.2 per cent; April, 5.2 per cent; May, 6.9 per cent.

The total cost of operating the Storekeeping Department for the year 1927 was $144,185 for 5256 employees. If this is compared with a total cost of $52,523 for the first six months of 1929, it will be seen that there was a saving of about $39,000 for this year in this one department.

It is believed that this saving is due largely to the bonus plan now in effect, and each one of these plans is showing equally good results.

The general bonus plan used for most of the other service departments is similar to that given for the Transportation Department, namely, an equal division or "split" of the "savings under department budget." This system corresponds to the Halsey premium system of wage incentive. This seemed the simplest and most desirable plan to use with such a large number of variable factors entering into the budget estimates.

TABLE 4 BUDGET DETERMINANTS FOR GENERAL AND SERVICE DEPARTMENTS GROUP BONUS PLANS

Symbol	Department	Approximate employees	Budget determinants K	$+$	Pn
015....	Cashier's office	15	$3000		18.5c. per employee in attendance
016....	Accounting and cost	29	3000		56.0c. per employee in attendance
017....	Timekeeping	78	3000		1.95% yard payroll
018....	Tabulating	23	800		$8.80 per 1000 cards
021....	Employment	10	500		0.29% yard direct labor
026....	Janitors	18	900		58c. per operative employee
029....	Watchmen	50	3000		0.89% shipwork labor only
030....	Machinery drawing room	26	2000		10% payroll of department
....[a]	Hull drawing room	11	400		3% payroll of department
037....	Correspondence	25	500		6% payroll 030 Division
041....	Plant engineers	25	3000		0.48% yard direct labor
052....	Material department office	52	4000		$1.01 yard employees in attendance
053....	Storekeepers	80	2000		$1.72 yard employees in attendance
054....	Transportation	83	8000		1.38% yard direct labor
055....	Drayage	27	800		0.96% yard direct labor
056....	Lumber storage	28	..		$3.07 per 1000 bd. ft.
058....	Steel stock storage	19	1250		40c. per ton of steel
060....	Production division	88	8000		85% yard direct labor
066....	Time study	34	A 1600		1.02% yard direct labor
			B ..		0.25% net gain on all operative department direct labor budgets
067....	Order	18	..		11.2c. per sq. yd. blueprints issued
	Total participating employees	739			

[a] Employees participating in machinery and hull-drawing-room group bonus plans do not include draftsmen. All drafting is done on a subcontract or piece-work basis.

Budget Formula: Up to "normal" output, budget B equals a "standby cost," constant K, plus variable expense which varies with the volume of work or service rendered Pn. That is, $B = K + Pn$.

Note.—Actual figures are given in many cases.

Rolling Average

The six months' rolling average is used because the monthly fluctuations in the actual cost figures for departmental expenses are naturally apt to be very great for service departments; in other words, a longer period than one month for averaging purposes enables each department to make some bonus earnings each and every month if the average costs for the previous six months are satisfactory. If there was used a one-month period only, there would be some months where no bonus money was earned and other months where the earnings would appear excessive. To put it another way, the six months' rolling average is really more nearly correct as a matter of costing, for the reason that many seasonal or abnormal charges, such as heavy repairs to equipment or other things of a temporary or unusual nature, may cause charges to fall in the cost records of one month which really are incident to several previous months.

Budget Formula

The general formula given in Table 4 for a budget (namely, $B = K + Pn$) is universal up to "normal output," and from Table 4 it will be seen that there are several different uses or meanings of P and n in various departments, expressed in words as follows:

Method	P	n
(1)	Standard or budget cost per unit n	Number of units measured; as, (*a*) prints issued; (*b*) 1000 bd. ft.; (*c*) tons of steel handled; (*d*) cards punched.
(2)	Cents per unit n	Number of employees in attendance in operative departments.
(3)	Cents per unit n	Number of employees in attendance in yard (whole plant).
(4)	Per cent of n	Dollars payroll of the service department (includes direct and indirect labor).
(5)	Per cent of n	Dollars payroll of the division to which service department belongs.
(6)	Per cent of n	Dollars direct labor of division.
(7)	Per cent of n	Dollars payroll of yard.
(8)	Per cent of n	Dollars direct labor of yard.

Organization and Functions

Since the management and operation of service departments embrace the whole field of management, of which a wage-incentive plan is only a part, although a very important part, as outlined, consideration should be given in more detail to the other factors of management if space permitted. Some features, however, will be mentioned. Real management of any plant or department in a plant naturally begins with organizing and defining clearly the functions or duties of each department; then comes the further assignment of duties to each individual in the department. Printed booklets or manuals have been prepared and issued for this purpose in the plant under discussion. These are educational and instructive to all concerned and of great aid in training executives and other employees. Further intensive and special training all along the line is of course the next step in the same direction. Proper relationships between departments, with coordination of effort without duplication or friction, is one of the great problems of management in a large plant such as has been described.

What Is Expected of Service Departments

The bonus plans described are mainly based upon a good financial showing by the service department itself; that is, the department should render service at the lowest practicable cost, provided that the service itself is not impaired. Quality of service is most important of all—whether engineering and design, storekeeping or accounting, or other service to the operative departments. The promptness and the reliability of service are also of the greatest importance. All service work should be planned and scheduled in detail, so far as practicable. The three main elements of good service, then, are (1) quality, (2) time, and (3) service cost. The measure of the result or effect of good service is the value rendered to, or benefit received by, the departments served. This usually shows up in reduced costs of direct labor and materials.

In the plant discussed there has been a reduction in direct labor costs on large high-grade passenger ships (such as the *Virginia* and *Pennsylvania*) of about 30 per cent during the past six years.

Advantages and Disadvantages of Bonus Plans

Advantages

(1) Simplicity. Easy to understand. Easy to operate at low cost. One man handles all these bonus calculations.

(2) Interest Factor. Creates a real personal interest on the part of every employee in improved service at minimum costs. Employees watch for waste in their departments. Thinking ahead is stimulated.

(3) Financial. Fairly immediate financial gain to a company after the system is effective in any department. Employees start earning bonus money, taking a great interest, however small the bonus. Average earnings of all service employees over their usual pay are about 9 per cent at present. The more they earn, the more profits the company makes.

(4) Compared to other plans, such as "stockholding" for employees in general, the bonuses more nearly reward the various employees and groups in proportion to their value to the company.

Disadvantages

(1) Most of the disadvantages arise from the extreme difficulty of setting correctly the bogeys or budgets, which can hardly be avoided. The formula $B = K + Pn$ is not absolutely correct, even up to "normal" output, and at normal output or above the budget line should droop or flatten out. The net result, however, in bonus payments is not at all serious—largely because of the protection against poor estimates or standards by the even-split idea.

(2) The plan described may not be regarded by some as "scientific," and in the usual manufacturing plant it may be practicable to improve over the conditions described. The authors have both had several years' experience in various kinds of manufacturing, which leads them to this conclusion. Offsetting this criticism, however, it is felt that an "immediate sure saving" of over $200,000 a year is preferable to a postponed possible saving, after years of more scientific study, of perhaps a larger amount. In fact, the present plans make it easier to go further and more scientifically into the whole matter. In office management in particular there is room for still greater improvement. The present plans have created and maintained an interest by heads of departments in any possible improvements that may be suggested for their departments. The problem of management of "creating and maintaining" the proper interest is probably the most difficult thing in the world to accomplish. Custom, habit, tradition, vanity, and prejudice are five arch-enemies to progress.

An Opportunity

The main theme of this paper is that of offering an *opportunity to all employees* in a plant to increase their earnings by some definite scheme of extra reward for extra thinking and action and at the same time increase the company's net earnings. In the large plant discussed incentives were already in effect before service-department bonuses were started, with excellent results not only for productive- or direct-labor employees, but for practically all executives, major and minor, including foremen and gang bosses. The service-department employees are entitled to as much consideration as other employees, and the supposedly insurmountable difficulties of giving them this consideration have at last been overcome in a simple and practical manner.

Appendix No. 1

Duties of the Production Engineer

The Production Engineer is responsible to the Production Manager for the performance of the production staff duties briefly described under the following headings. The Production Engineer acts for the Production Manager in the absence of the latter.

061 *Cost Control*
- Expense and labor budgets by departments
- Critical comparisons of actual cost with budgets by departments
- Cost system development.

061 *Master Schedules*
- Master schedules, general planning and allocation of work
- Coordination of material control system with the master schedules
- Critical comparisons of actual progress with master schedules and expediting work as required to meet delivery dates
- Reports for progress payments.

062 *Estimating*
- Cost estimates for all work except for ship repair and plant work
- General review of ship-repair estimates amounting to $10,000 and upward
- Determination of the desirability of work to suit production facilities
- Delivery dates for all proposed work
- Job orders for all work except for ship repair and plant work.

063 *Testing Laboratory*
- For duties of this department see separate heading in this section.

064 *Locomotive Engineering*
- Inspection records for locomotive repairs
- Orders and material records for new material required
- Miscellaneous railroad orders
- Progress reports for locomotive repair work.

065 *Inspection Department*
- For duties of this department see Section I.

066 *Time-Study Office*
- For duties of this department see separate heading in this section.

067 *Order Department*
- For duties of this department see separate heading in this section.

068 *Welding Research Department*
- Development and extension of welding and cutting to all classes of structural work, and cooperation with the design, sales, and operative departments to this end
- Welding and cutting research and tests
- Recommendations on mechanical methods and on the design and purchase of equipment and supplies for welding and cutting
- Standardization of welding and cutting practice
- Supervision of training and certification of welders.

Note.—The Assistant Production Engineer will exercise such supervisory duties in the above list as are assigned to him by the Production Engineer.

Duties of the Testing Laboratory

This department is a testing service station for the Yard and is under the immediate charge of the Metallurgist who reports to the Production Engineer. The work of this department consists of making determinations of the chemical and physical properties of purchased materials that may require analysis, control of the characteristics of outgoing materials to specified requirements, and such technical and research service as may be rendered for the improvement of materials and the regulation of processes as mixing, melting, and heat treating, all for the general purpose of obtaining better products at lower costs.

This work, including the necessary compilations of data and reports, is carried on under several headings which may be given briefly as follows:

1 *Chemical*
- Control of foundry analyses for iron, steel, brass, bronze, and other metals
- Testing of incoming materials and outgoing products.

2 *Metallurgical*
- Metallurgical research and investigations
- Development of specifications and standard practice instructions
- Heat treating control
- Microscopic examinations.

3 *Physical*
- Preparation of test specimens
- Testing operations as pulling, compressing, bending.

4 *Fuels and Lubricants*
- Comparative analyses of fuels as coal, coke, fuel oil, and gases; lubricants as oils, greases, and compounds.

5 *Paints and Varnishes*
- Comparative analyses of ingredient materials and developing, formulating and testing of paints, varnishes, and lacquers.

6 *Research*
- Investigations of troubles in established processes
- Development of improved methods or materials.

Inspection System

1 *Date in Effect.*—The following inspection system has been agreed on after consultation with the superintendents and material agent, and is to be followed from August 1, 1927. Departures from this system are not to be made without consulting the Production Manager or Production Engineer.

2 *Purpose.*—To maintain the company's reputation for good workmanship, to keep incoming material up to specifications, to avoid delays and reduce the cost of correction by detecting errors before material has been worked into the final assembly or shipped to the purchaser.

3 *Scope.*—Inspection shall cover incoming material, workmanship, conformity to drawings, specifications and orders, and the general suitability of the material or part for the service intended.

4 *Process Inspectors.*—Detail inspection of work in process will be made by inspectors who will report directly to the division superintendent. In the larger shops this work may be divided among several men but in the smaller shops may be handled by one man. These inspectors will devote a part of their time only to inspection, as they will also check detail progress and quantity and in some cases do piece-work counting.

5 *Product Inspectors.*—In addition to the process inspectors there will also be a group of product inspectors, reporting to the Production Engineer, who will make final inspection of all finished or partially finished material to be delivered by one division to another, or to a warehouse, ship, or outside purchaser. Each product inspector will keep informed as to the general progress of work in his territory so that he may be able to give information relative to delivery dates.

6 *Duties of Inspectors.*—Process inspectors will pass on work in process with the idea of eliminating or correcting defective material or improper workmanship in the stages before the parts reach the product inspector. They will consult with the product inspectors relative to the suitability of material for a job in case defects or errors are discovered and will arrange for replacing all condemned material. Particular attention will be given to correct heat numbers and piece marks, or other identification marks. Process inspectors will also be responsible for the correct dimensions of all parts machined to fit other work which is not readily available for checking by the product inspector, such as stern tubes, bushings, cylinder liners for repair jobs, etc. Product inspectors will pass chiefly on the general quality of work, its adaptability to the service for which it is intended, the correctness of dimensions affecting final assembly after leaving the shop (except as noted above) and the agreement with the requirements of the U. S. Steamboat Inspection Service, the Classification Societies, or other inspection agencies. They will arrange for the presence of purchasers' representatives or the representatives of inspection agencies on all tests or inspections on which their approval is required. They will pass on all corrections of major errors in shop work and the reclaiming of defective castings and forgings and will see that the approval of the owners is obtained if required. They will consult freely with the superintendents and the drawing room heads to insure corrective work being done in the best possible manner, and will pass on to the drawing rooms, through the Production Engineer, suggestions for improvements in design discovered in inspection. They will also observe work in process, particularly on large parts, wherever preliminary inspection of this nature will facilitate final inspection and avoid setting up the work again. Product inspectors will also supervise the loading for shipment of all material requiring special cars, or special blocking or packing.

7 *Inspector's Decision.*—In case of doubt as to interpretation of drawings, orders, specifications, or other requirements, the decision of the Chief Inspector will govern, subject to appeal to the Production Engineer whose decision will be final.

8 *Drawings and Orders.*—When necessary the product inspectors will be provided with copies of the shop orders, specifications, and drawings, but wherever it can be done without hindrance to the shop work, they will have access to the shops' files or drawings and orders, to avoid duplication.

9 *Reports.*—Process inspectors will make reports as may be required by their superintendents. On all material to be shipped away the product inspectors will submit promptly to the Material Department a detailed inspection report listing each piece, or group of pieces, to be shipped. The Chief Inspector will report daily to the Production Engineer on all major inspections, tests, and corrections.

10 *Organization of Product Inspection System.*—One Chief Inspector to whom all product inspectors will report. The Chief Inspector will cover special jobs and make such reports and investigations as may be required by the Production Engineer. One inspector for the main machine shop, brass machine shop, and erecting machine shop to inspect valves, manifolds, pipe castings, and all other fittings made for steam, water, and fuel oil pipe lines. One inspector for all other work of the main machine shop, brass machine shop, erecting machine shop, and for all work of the boiler shop. One inspector for the foundry. One inspector for the blacksmith shop, forge shop, and the H. F. and P. group. One inspector for the north side structural shop and hull assembly division for work to be shipped to outside purchasers. Additional inspectors and other duties will be added as conditions may require.

11 *Physical and Chemical Inspection.*—All physical and chemical tests will be in charge of the metallurgist whose duties are described under testing laboratory in Section III addenda.

12 *Inspection of Incoming Material.*—The material agent will arrange for the inspection of all incoming material. This inspection will cover quantity, quality, conformity to purchase specifications, and condition on receipt of shipment. An inspector, qualified by experience for the work, will be designated by the material agent to inspect all incoming steel except where the material agent is satisfied that thorough mill inspection has already covered the ground. Lumber and other bulk material will be handled in the same manner. In all inspection of an engineering or special nature such as large castings, machinery, special fitting, or equipment, the material agent will call on the Production Engineer for technical assistance and the Production Engineer will, if necessary, consult the drawing room ordering the material. The same procedure will be followed in case important material is received of questionable quality or in damaged condition necessitating corrective work in the yard. Each case in which inspection shows the purchase specifications to be incomplete or faulty will be reported to the Production Engineer in order that satisfactory specifications may be given on future purchases.

Duties of the Time-Study Department

1 Make time studies and collect data on all classes of work
2 Get this data in such shape that it can be used for estimating and for establishing piece-work prices
3 Establish units of measurement for all classes of work
4 Suggest improvements in methods, tools, fixtures, and equipment wherever possible to increase production
5 Promote the cooperation of the workers with the incentive systems
6 Furnish the superintendents, assistant superintendents, or foremen with any data they may require which we have, or can collect
7 Establish piece-work prices in conjunction with Foremen
8 Write all piece-work price tickets
9 Prepare uniform working of piece-work tickets for the respective classes of work to be done
10 All piece-work prices to be set before the work begins
11 Check totals of piece-work prices with labor budgets
12 See that approved piece-work prices are not increased or decreased, except for increase or decrease in work. When prices are increased or decreased, a statement in writing, covering in detail the reasons therefor, must be submitted and agreed upon
13 Furnish any data required by the Production Engineer for estimating purposes
14 It is to be understood that no piece-work price is to be put into effect until approved and signed by foreman of department or some one whom he may designate, and by some one in the Time Study Department.

Duties of the Order Department

The principal work of this department has its beginning in the receipt of plans from the several drafting offices in which they are made. This work consists of taking from the plans or bills of material all items to be manufactured and issuing production orders for them to the departments to do the work; making out and issuing identification tags to accompany each part through its interdepartmental routing; making from the plans and issuing the necessary blueprints to the shops and departments to do the work called for.

This work, and certain other duties carried on by this department, are more particularly described under the following headings:

1 *Production-Order Section.*—It is the duty of this section to write the production orders from the plans or other sources of design authority and to indicate on the orders the interdepartmental routing for each item from its source to destination; to make out the tags to accompany and identify each item; to apply the routing to the material control record sheets; and to make out the distribution lists for blueprints for the departments doing the work, superintendents offices and others concerned. It is provided in the routine of this work that the distribution to departments of copies of the production orders and blueprints, material-control record sheets, and the route of the identification tags shall agree with the routing shown on the production orders. In connection with the duties of this section it may be noted that certain classes of work, as built-in structural work, do not require detailed routing on the production orders. For this class of work the same care is exercised in making out the distribution lists for blueprints for all concerned as for work going through the manufacturing departments. Certain miscellaneous duties are performed by this department as it affords a convenient center in which they may be handled; as, catalog of material stores symbols for inventory purposes, catalog of drop forgings and balance-of-stores work for this class of material, summaries of weights placed on board ships and similar weight summaries as needed, multigraph work.

2 *The Blueprint Section.*—This operates all blueprint-room equipment, makes and delivers the blueprints and other reproductions as called for by the print lists and keeps suitable records to verify their distribution. This section also clears back to the files the tracings and other original sheets after the prints have been made.

3 *Weight Office.*—The work of this office consists principally of weighing, or compiling weights from authentic sources, of designated groups of material placed on board ships and reporting these weights to the Estimating Department. Similar weight reports will be made for certain classes of hydraulic work and other products as required.

Duties of the Employment Manager

The employment manager is responsible to the management for the supply and training of suitable labor and for the promotion of harmonious industrial relations. This work is organized under several headings which may be given briefly as follows:

1 *Employment Office*
- Correspondence
- Interviews
- Placements
- Ratings
- Transfers
- Re-ratings and promotions
- Furloughs
- Terminations

2 *Employment Records*
- Service
- Occupational
- Attendance
- Earnings
- Turnover by departments

3 *Employment Service Information*
- Addresses
- References
- Board and lodging
- Houses and apartments
- Miscellaneous service work

4 *Training*
- Apprentice school
- Job training

5 *Industrial Relations*
- Employees' representation plan
- Safety committees
- Plant publications
- Other activities.

Duties of the Plant Engineer

The Plant Engineer is responsible to the management for providing suitable buildings and equipment for carrying on the productive work of the plant in an economical and expeditious manner. It is his duty to advise with the various department heads and investigate any requests for new equipment or buildings, changes in locations of present equipment or alterations in the design to increase efficiency, and to design any needed special equipment which cannot be obtained from the usual sources. This work is organized under the following headings:

1 Office Staff
2 Buildings and Structures Section
3 Machinery-Design Section
4 Small-Tools Section
5 Electrical Section

1 *The Office Staff* in addition to other duties keeps records by numbers and locations of all numbered machines and other equipment throughout the various departments. This section also takes the monthly readings of all meters measuring electric current, gas, and water purchased and of such other meters as are installed to record the electric current, gas, water, and steam used in various parts of the works.

2 *The Buildings and Structures Section* is in charge of a structural designer who is capable of designing buildings, cranes, crane runways, etc., and of advising the overload load carrying capacity, if any, of any bridge crane, jib crane, or building structure in the yard. Also, in this section there is a building inspector whose duty it is to inspect all buildings, estimate the cost of repairs or proposed changes in the arrangement of buildings or their equipment and to see that repairs and changes are carried out in a satisfactory and workmanlike manner.

3 *The Machinery-Design Section* is in charge of a machinery designer who is capable of designing special equipment and advising as to the overload capacity of existing equipment. This section also has charge of the design of special tools, jigs, and fixtures required for unusual jobs.

4 *The Small-Tools Section* is in charge of a small-tools inspector who has charge of the inventory of small tools, the interdepartmental transfer of small tools, tests, and standardization of small tools. This inspector's duties also include the inspection of all requisitions for small tools to be sure that only those that are standard will be ordered.

5 *The Electrical Section* is in charge of a designer who is capable of designing, laying out and ordering switchboards, control equipment, and motors, and of determining wire sizes, etc., for power transmission.

Emergency machinery repairs amounting to $50 or less are taken care of by the repair department directly, all charge being made directly against the machine number. For major repairs or general overhauls the work is covered by a foreman's repair order which is submitted to the Plant Engineer who issues a repair job order covering the work. In this way the charges are segregated so that in some cases, when so authorized, the departmental budgets may be relieved of unusual special expenses for which they cannot be held strictly responsible.

Upon requests from department heads the Plant Engineer issues all special equipment orders to cover machines, tools, jigs, and fixtures which are purchased or manufactured to execute particular jobs or contracts. Upon completion of the work these special equipment orders are closed and final returns are available for the inspection of those interested.

The Plant Engineer shall also be responsible for all costs for new small tools charged in asset account 6 and for the quantities of such tools acquired either by purchase or by being manufactured in the yard.

Discussion

Felix W. Zuelow.[3] In many cases, the company with which the writer is connected has established variable budget standards

[3] General Electric Company, Schenectady, N. Y.

on service labor for direct operative departments, applied to accurately time-studied productive operations; while in the case of general service departments, the several functions performed are carefully analyzed, and task standards established on all major controlling factors involved.

Obviously no real objection can be made to the point that it is preferable to secure an "immediate sure saving" by the methods described in this paper, rather than await more certain and possibly larger savings based on years of more scientific study, until a point is reached when there is a reasonable cause for doubt whether real savings are being effected under such procedure. While it is perhaps easier to go further and more scientifically into this whole matter of applying incentive plans to service departments, after comparatively rough, overall standards of performance have been tentatively established and tested out, nevertheless, it cannot be over-emphasized that such further and more scientific study into this subject is imperative, if satisfactory and permanent improvements along these lines are to be properly guaranteed for the future.

PAUL HECHT.[4] The very clear and detailed exposition of the subject of budgeting and wage incentives for service departments, as set forth in the paper, rather restricts the field for discussion, especially by one who is as sympathetic with the subject under consideration as is the writer.

The Newport News plan offers incentive payment to all employees of the service departments and is, therefore, more comprehensive than the plan at present followed at the South Philadelphia Works of the Westinghouse Electric & Manufacturing Company (hereinafter referred to as South Philadelphia), which offers incentive payment only to the department heads, superintendents, and foremen as the case may be, and to certain keymen within the departments who are able to influence and to exercise some control over expense. Furthermore, at South Philadelphia the incentive plan is not confined to those departments which Messrs. Ferguson and Blair classify as service departments, but applies also to the supervisors and foremen of the so-called productive or operating departments. Plans are being developed toward putting the rank and file of the service departments on an individual incentive basis so that work in excess of a measured standard, on which the regular wage or salary is based, will be compensated for by an increased wage allowance.

The difficulty of setting up a proper "expense budget normal" can be appreciated only by those who have had to attempt such a set-up under conditions prevailing in the Newport News plant and at South Philadelphia. As at Newport News, so at South Philadelphia, practically none of the work is duplicate work or of a repetitive nature. While the work at South Philadelphia is not seasonable to the extent prevailing at Newport News, there are such wide fluctuations in volume that on a theoretical basis the operating force in the plant could be varied from one to five or often six times a year.

Past records of performance intelligently scrutinized are, of course, the only means of determining a standard expense budget. The detail of setting up this standard differs in some respects at South Philadelphia from the method followed at Newport News. At Newport News, the normal budget upon which the bonus plan was based did not exact any immediate betterment in costs over past performance before the zero or starting point of bonus earnings could be reached. While such a method would be equitable if all of the participating departments were operating at equal efficiency before incentives were established, it is unfortunately a fact that such a condition does not exist in the average plant made up of many departments and thousands of employees. It is conceivable, therefore, that supervisors who have been conducting the operations of their departments with a high degree of efficiency from an expense standpoint would have greater difficulty in making a showing than would those who had been less energetic in expense control, and as a consequence those supervisors who put forth super-effort before incentives were introduced might suffer in bonus payment after incentive measures were applied as against those who had not exerted such extra effort. This is manifestly unfair. At South Philadelphia, therefore, while past performance over a period of several years was taken as a basis, practically all expense accounts were modified before bonus earnings could begin. This review was made jointly by the supervisor of the particular department involved and those members of the executive staff who were generally familiar with the operations of the plant as a whole. Some of the expense items were increased, and others decreased, and when the different departmental budgets were finally approved, they stood at figures ranging from slightly higher than recent past performance to reductions as great as 20 per cent below such performance.

In this connection it should be pointed out that the South Philadelphia plan provides that if a deficit is incurred in any department during any month, such deficit must be made up in succeeding months before bonus payments will be made. In order to avoid an undue hardship on those departments whose budgets had been reduced, a four months' moratorium was allowed when the plan was introduced. Under this moratorium each department was allowed a period of four months in which to reduce its expenses to the budget level. Any deficit incurred during these four months was not charged up against the department as an amount to be recovered or made up in succeeding months before bonus payment would begin. The Newport News plan apparently makes no provision for a penalty in case of a fall-down.

Another point of difference is that the standard expense allowance at Newport News is determined by either the total labor cost of the department or the total direct-labor payroll. This was considered at South Philadelphia, but owing to the wide volume fluctuations previously referred to, making it necessary at times to conduct from 35 to 40 per cent of the operations on an overtime basis, with its attendant overtime bonus, it was felt that labor earnings would not provide a proper standard and, therefore, productive hours were set up as the determining base. This procedure likewise controls any tendency that might develop in the occasional instance for the supervisor to build up his payroll dollars by working overtime when more careful planning might possibly avoid its necessity.

The South Philadelphia plan recognizes two kinds of expense, fixed and variable. Instead, however, of setting the fixed or standby figure at a mythical zero of work in any one department, which is practically impossible of determination, it was set at the more easily determinable point representing the normal operation of the department, and the factors were established for its modification within such ranges above or below normal as might reasonably be anticipated, say a year in advance. The normal or standard variable expense allowance divided by the normal or standard production hours gives the variable rate per hour.

Another variation from the Newport News plan at South Philadelphia is that the bonus is divided into two funds. Fifty per cent of the bonus, known as the departmental fund, is paid to the individual participants in cash provided there are no outstanding debits from former months, and the remaining 50 per cent is credited or debited, as the case may be, to an annual reserve fund, distribution of which is made once a year. All who participate in one fund also participate in the other, but

[4] Assistant to Vice-President, Westinghouse Electric & Manufacturing Company, South Philadelphia Works, Mem. A.S.M.E.

not necessarily to the same extent. Participation in the departmental fund is predicated upon the value of the service of the individual to that particular department, whereas participation in the annual reserve is predicated upon the potential contribution of the individual to the economical operation of the works as a whole, the theory being that no one department stands or falls by itself, and that there must be developed a spirit of cooperation among departments as well as among individuals, each helping the other to reduce its expenses to the economical limit and sharing in whatever benefit may be derived from such cooperative effort.

The results achieved thus far have been gratifying indeed. Costs have been decreased in innumerable ways and the earnings of employees have increased. An interest has been aroused in cost reduction which was not manifest before the incentive plan was introduced, and this interest will surely result in cumulative reductions in the years to come.

CARL E. JONES.[8] The "service departments" are outlined in this paper as including general office work, drafting work, accounting and cost departments, material supply, storage and transportation, time-study departments, and a great variety of other functions. The paper mentions also that the management of the service departments is complicated by the nonrepetitive character of the work, and also by the fact that practically all work is contract work, and by the further fact that the ship-repair business is somewhat of a seasonal business, with a large rush of work at various times and at other times this work is slack. There are eight specific points and two general aspects of the problem which the paper raises. The specific points follow:

1 One of the principal values which the speakers have claimed for their system is that it gives an opportunity for reward offered to those employees whose work cannot be definitely measured or standardized in the ordinary sense, who never before have had a real opportunity for increased earnings based upon their individual or group efforts and results.

The employees of the so-called service departments are thus placed under one heading by themselves, as opposed to the other workers whose number of units of work are theoretically more open to measurement. Whether the exact performance of each operator within many of the service departments cannot be measured more definitely and much better than previously has been attempted by most establishments is open to discussion.

For example, in several offices of large industrial plants the exact performance of each individual employee in the transcribing, correspondence, billing, accounts receivable, and certain other departments is measured and compared with predetermined standards which have been set. The pay of each employee, supervisors not included, is thus increased by whatever contribution in extra effort he or she has put in. The excess remuneration to the employee thus comes simply on the basis of individual performance, rather than as a portion of the saving made by the departmental group.

2 The paper mentions that group bonuses can be applied to the work of service departments where one cannot measure separately the output of individuals on account of the great variety of functions performed by nearly every person in these departments. Unquestionably there are many individuals in the service departments of all organizations whose work will not submit itself to any type of measurement. This should not make one close his eyes, however, to the fact that other employees are on jobs where time studies and fairly exact standards may be set. With the advent of machine methods for invoicing, keeping records of accounts payable, and accounts receivable, machine-bookkeeping for control, plant and costs ledgers, and the like, increasing opportunities are coming for determining the standard base pay and the extra pay due for extra exertion of each clerical employee.

In factory warehousing work, the installation of gravity conveyor systems has likewise tended to functionalize jobs, so that many of them are nearly as subject to time studies as are many so-called producing department jobs.

3 In order not to handicap the participating group at the outset, the budget normal upon which the bonus plan was based (according to the authors) did not exact any immediate betterment in costs over past performance before the zero or starting point of bonus earnings could be reached.

This point is very well taken. Whether the enterprise be one of ship-repairing, manufacturing, or retailing, the same fundamentals apply. If a group of employees, in order to make a bonus, had first to accomplish a certain amount of savings with no portion accruing to them, they would not consider the game worth while playing, and would not cooperate at all with the management in the installation of the plan.

4 The final written plan should not only give in concise form the results from the cost studies (according to the authors), but should state also which employees are to participate on the bonus and to what extent they participate. The plan generally includes a statement as to the quality of service rendered not being impaired or the plan is void. This is for the purpose of preventing a reduction of cost by lowering the standard of the service.

In this connection it is well to raise the subject of starting such a new procedure merely upon the initiative of the management versus starting such a system after the careful collaboration and cooperation between the management and the duly authorized representatives of the department or division affected. When the representatives of the employees go back to their fellow-workers with the plan as their scheme and preach it in that light, the proposed system has a certain backing it would fail to have if presented merely by the members of the management.

5 The subject just given has included a statement that the biggest factor in getting this plan over is "selling" it to the men in the department. This takes a lot of time and salesmanship, and for the first two departments that were put on this plan, one man lived right with them for the first two months, and it was his job to suggest every saving possible to the foremen.

Salesmanship and tact in suggesting savings would certainly be required during the early stages of any such plan. Once the initial suspicion and inertia of the employees were overcome, progress should be easier. If the management should place such an efficiency man in a department, it would probably be beneficial to introduce him as the helper of the employees in eliminating waste and thus getting extra pay, rather than to introduce him as the representative of the management while the system was started.

6 With all of the service departments now working on some kind of an incentive system, which means receiving extra pay, this thought comes to mind.

There is a constant urge, almost an ever-present necessity, for manufacturers and other enterprisers to reduce their costs. In the long run, many concerns have found this necessary in order to remain in the game. From one point of view, this incentive plan does reduce costs by the one-half of the saving kept by the company. There is the further thought, however, that if such a plan were to be adopted by manufacturers generally, and the other half of the saving were promised to the workers for time indefinitely ahead, trouble might arise some time in the future. Still greater competition might arise some day, the

[8] Dennison Mfg. Co., Framingham, Mass.

elimination or reduction of the group bonus plan for the service departments might be necessary for the preservation of the company, and still because the workers had come to think of this saving as their right, trouble might arise through any such elimination or reduction. This is mentioned merely as a possible eventuality.

7 The authors mentioned that a six months' rolling average, or moving average, is used because the monthly fluctuations in the actual cost figures for departmental expenses are naturally apt to be very great for service departments; a longer period than one month for averaging purposes enables each department to make some bonus earnings each and every month, and if the average costs for the previous six months are satisfactory.

This is undoubtedly very good procedure from the viewpoint of maintaining hearty interest in the plan upon the part of the employees. Nothing would be more discouraging to them, and more effective in breaking up the morale, than to be informed that they received no bonus for a given month simply because very expensive repairs had been charged into the costs that month. The use of a rolling average tends to remove the possibility of any such occurrence happening.

While a six months' moving average is probably quite satisfactory for a ship-repairing establishment, a twelve months' moving average would probably be more satisfactory in many manufacturing and retailing companies which are subject to marked seasonal fluctuations throughout the year.

8 One of the last points of the authors was that the service department employees are entitled to as much consideration as other employees, and the supposedly insurmountable difficulties of giving them this consideration have at last been overcome in a simple and practical manner.

This point is well taken. The percentage of service department employees to the remaining employees is sufficiently high in many concerns today, so that they should not obtain the idea that any discrimination is being made against them. If extra remuneration plans are in operation for producing department employees, it is certainly a strong point to have some such plans for the service department employees also. The difficulty of preparing incentive plans for service department employees should gradually be lessened as tasks tend to be standardized in many instances through the introduction of more machines into service department work.

The remaining two points deal with the topic in its broader phases, as follows:

1 Around 15 or 20 years ago, G. Charter Harrison began making us familiar with the system of cost accounting based around standard or predetermined costs, as opposed to actual costs. Once the standard costs were approved and put into operation, executive attention could be directed mainly into an observance of the deviations of the actual costs from the standard costs, rather than a study of the actual costs themselves. When budget figures in manufacturing departments first came on the scene, they tended to make a third figure; more recently, however, the budget has been woven into the cost accounting of the producing departments of some industrial concerns, and the budget figure and the standard or predetermined cost have become merged into one and the same figure.

During the last few years pioneer research work has been done in the realm of the supplementary or commercial and administrative costs of doing business within manufacturing companies. Detailed studies of the costs of given operations within the clerical, warehousing, and other service divisions of the enterprise have been made. It may be only a few years before standard costs are developed for these divisions, in many concerns; the given service department will then be charged with its actual cost and credited for its units of production at so much per unit; and its performance will be measured by the deviation from the predetermined cost or budget figure just like a producing department. Yet while this may not be possible for all service departments, it should still be considered as a desirable goal, for in so far as this can be done a budgeting and cost control over these divisions results.

2 Finally, with group-incentive plans of the type where one-half of the saving is given employees in their relationship to the profits of the entire company, the more a given department saves, the more will be the profit, or the less the loss, of the entire company, due to the saving of this one department. There may be years, however, when the profits for the entire company may be negligible or non-existent, even though the employees of a given service department might have made considerable savings and the employees of that department might still consider themselves entitled to their group bonuses. This raises the thought that possibly there might well be developed some possible interconnection between group incentive plans and the total company profits in the lean years. Perhaps this is not necessary or desirable in the case of this particular ship-repairing company, but it seems like a point which should be thoroughly considered before the adoption of such a plan by other concerns in either the manufacturing or mercantile fields.

P. L. Dildine.[6] It requires courage to criticize a successful proposition. This paper describes a wage-incentive method which has actually been applied to service departments with profitable results. It is to be presumed that the authors do not present this plan as being flawless. It accomplishes, however, the major purpose of which it was designed—namely, the reduction of costs. That is always worth while, provided the economies thus effected do not later react in greatly increased costs and loss of business to the company. It is the purpose of this discussion to suggest for consideration possible weaknesses in the plan, as well as possible improvements.

The authors do not state whether or not a revision was made in the plan on January 1, 1929, or at the subsequent six-month interval. It would no doubt be interesting to know what, if any, revisions have been made since the wage-incentive plan was inaugurated.

In connection with these revisions, if any have been made, it is evident that the continued future success of the plan must depend largely upon the confidence of the employees in the management. As long as the employees feel that the budgets have been justly established, that confidence will be maintained and operation costs will be kept on a low level. If the budgets are at any time revised downward without justifiable reason, so that difficulty is encountered in earning a satisfactory bonus, the confidence of the employees in the management will be threatened. This may eventually result in disgruntled employees and high costs of operation. This phase of the plan can only be tested after the plan has been in effect for several years.

It is also worthy of note that due to the method of establishing the original budget, the department operating with the greatest inefficiencies participates for the first few months in the largest bonus. That is, the department which, prior to the inauguration of the plan, is operating at "rock bottom" costs has less of an opportunity to reduce further the cost of operation, as compared with the inefficiently managed department. A premium reward is thus paid for the first few months at any rate for inefficient management. It would appear that a more accurate basis than past experience could be obtained for establishing the original budget. Time studies have been employed for such departments in determining the effectiveness of labor

[6] Engineer in Charge, Time Study, Standards and Budgets, B. F. Goodrich Rubber Co.

and the establishment of labor cost budgets, even though piece rates or direct bonuses are not used for direct compensation of the employees. The degree to which labor is fully utilized in a department is ofttimes a pretty accurate measure of the degree to which materials and equipment are utilized.

Furthermore, in the concern with which the writer is connected, the employees in several corresponding service departments mentioned in this plan are compensated by direct premiums paid to them under the Bedaux plan, after the work in the departments has been properly time-studied. These departments are timekeeping, tabulating, plant transportation, motor trucks, warehousing, and janitor service.

It is also to be realized that the bases used in this plan fluctuate from time to time due to the varying effectiveness of the management in the production or base departments. Thus, the number of employees in attendance in a production or base department may vary from time to time, not necessarily because of any variation in the volume of work, but rather because of the variability in management effectiveness. This is offset to some extent by use of the moving average in the determination of monthly budgets, expenses, and bonuses. It is conceivable, however, that the number of employees in attendance over a period of months may be in excess to actual needs, thus increasing unduly the budget and consequent bonus for the transportation group or any other group, the bonus for which is computed on the same basis.

Despite these possible shortcomings, the Newport News Shipbuilding and Dry Dock Company is to be congratulated on its courage to attempt such an undertaking. The results which are being attained are the same as all industrial managers are striving to attain. The authors suggest that the plan "may not be regarded by some as scientific." The savings effected are being immediately reflected in the accounting records of the company. The plan is sufficiently flexible as to permit the application of scientific methods from time to time as experience dictates.

K. T. Keller.[7] Most of the fundamentals are applicable in any manufacturing plant. It is felt, however, that these fundamentals could be applied more directly by means of predetermined operating costs which would be the governing factors in balancing the budget for all departments, including the service departments, with the productive output at a level which would assure a profit from the plant operations.

When a six months' average of expense is used, there is no indication that the expenses for the various departments were normal or that the volume of output justified the expense, even if the expense was considered to be at a normal average. Hence, the service departments should first be studied, in the following respects:

To determine the necessity or relative importance of the work, as non-essential functions may be developed through errors in judgment or they may be continued after a temporary necessity has passed and relatively unimportant functions may be overdone.

To determine the man-power required to carry on the necessary functions. Requirements should be based on actual time studies, either of the operation itself or of the operation served, wherever possible, as the time studies provide a direct method of measuring the non-productive in proportion to the productive. The requirements should be divided into variable and constant (or stand-by), but the constant should be limited to the fixed charges and to the minimum expense necessary for plant protection and maintenance, and for the barest skeleton of an organization, inasmuch as there are very few operations which cannot be curtailed or suspended when production approaches zero.

To determine the responsibility according to the department which will authorize an expenditure. In budgeting or in setting up a bogey for budgeting, it is believed that the responsibility should be fixed on the department originating an expenditure. Hence, the plant engineer would be responsible for all maintenance rather than giving any allowance to the various other departments. The expense as a whole should be divided to show the controllable and non-controllable. The non-controllable would include expense which has no relation to production and cannot be controlled by the manufacturing supervision, as depreciation, taxes, insurance, write-off for inventory shrinkage, plant protection, accounting, etc. The controllable would include inspection, stock handling, tools, supplies, etc. This separation in the budgets and in the expense statements shows the non-productive expenditures which should vary proportionately to production and also shows where it is possible to reduce when adjustments are necessary.

The complete study of the expense should be made on the basis of the requirements when the plant is producing on an average basis. The expense by departments and in total compared with the average productive labor gives the normal burden percentages for the plant and for the various departments. This percentage should be used in calculating the selling price of the product and should be the permanent bogey or fixed burden for controlling the budgets for all expense, excepting the fixed charges. The application of the bogey percentage against the productive labor for any schedule would give the permissible variation in the expense. The result is a standard manufacturing burden cost.

This plan does not provide a general incentive plan for expense reduction, but incentive wage plans can be incorporated wherever applicable. However, when the expense is properly studied, and the budgets controlled accordingly, there is no margin over requirements. Rather, it requires careful supervision to keep expenses within the budgets. Requisitions for additions to the force and for purchases of material must be checked with the budgets and properly approved.

The cost of operating this plan is very small. A budget supervisor and one or two assistants are all the special force required. The time study, employment, and timekeepers are tied in to the labor control. The material department, tool stores, and purchasing department are tied in to the material control. Expenditures not included in the budgets are not authorized. The accounting department makes daily reports of expenditures which are checked against the budgets. An annual bonus may be used as an incentive for the supervision.

It is apparent the plan set up is from actual findings and could be improved by actual studies.

C. W. Lytle.[8] The cause of good management is distinctly furthered by this paper. Although the authors may not be the first to apply job standardization and incentives to service departments, the thoroughness with which they have made the application and the very scale of the work makes the case peculiarly valuable. The paper might equally well have been named "Standardization of Work in Service Departments." In fact, this phase of the subject takes up the bulk of the paper. On the other hand, it has been the difficulty of such standardization which has delayed the application of incentives to this work, and the incentive is of course the immediate object of such work. As a student of incentives, therefore, the writer is glad the authors have given the paper an incentive title and this title will lead many to read it who are interested in the incentive question. It would seem that the procedure here described

[7] Dodge Brothers Corporation, Detroit, Mich. Assoc. A.S.M.E.

[8] Director of Industrial Cooperation, New York University, New York, N. Y. Mem. A.S.M.E.

is the most practical for such work. The detail would naturally vary. The formula for the budget task is made up of two parts, a constant and a variable, the former representing that amount of cost for the given department which is irreducible whether the department is producing or not. The latter part is a simple product of some carefully selected factor and the number of men or dollars involved. In short, the fundamental formula is not new, but is here presented in such a way that it is likely to be given renewed attention.

In explaining the use of this general formula, the authors mention that there are errors involved, but that they are inconsequential on account of the sharing feature of the incentive arrangement. This is an old principle—the principle which led Mr. Halsey to use the constant sharing type of earning arrangement at a time when all tasks were estimated and therefore were subject to considerable error. Graphically, this means that on a two-variable chart, the horizontal axis being efficiency and the vertical axis being wages, an estimated task is usually anywhere from 40 to 65 per cent of the more accurately set tasks in direction production. The earning curve in a sharing plan therefore starts at a low task point and reaches the desired high-earning field at the efficiency point most likely to become the location of average response. Conversely, these earning curves avoid the possibility of reaching too high an earning field for the average response point. In short, then, the selection of a constant sharing type of earning curve is exactly the correct practice for this kind of a task in shop or office.

What appears to be a very different matter is the practice of adding the amount of premium to the budgeted cost at the end of each successive month. No doubt the reason for this is to make the budgeted task include the whole labor cost whether the work is done with a large amount of day wages and small premium or a less amount of day wages and a larger premium.

From a cost-accounting point of view this is justified, but from a psychological point of view it certainly is not. It is a situation where the wage practice should be somewhat divorced from the costing practice. In fact, there seems to be no reason why the task cannot be equally well measured by all costs exclusive of premium and the factor adjusted so as to make the premium whatever it needs to be. It is certainly a difficult practice to justify to employees and might be interpreted as a new form of rate cutting.

The Rowan variable-sharing plan substitutes for the arithmetic fraction of sharing a variable or algebraic fraction of sharing which allows less and less premium as the efficiency increases. The fraction is so fixed that the maximum wage including premium can never exceed twice base wages, and in practice can never come even near this amount. This plan is mentioned because it has never seemed fair to American employers and is not used in this country, excepting for tasks extremely onerous.

Now, if the plan under discussion needs to have extreme protection for the employer, it can do so by using the Rowan principle. The writer is not prepared to recommend that principle very highly, but it is preferable to the practice of allowing the premium of a previous month to affect the task of a successive month. Perhaps this part of the paper is misunderstood, but in any case the authors should give their attitude on this point.

The authors have been most modest in describing their achievement. A great deal of their success has been due to their spirit of enthusiasm and their very human pains taken in the matter of training.

Authors' Closure

The discussions have been very much to the point, and bring out several important features of budgeting (or task setting) and bonuses which should be considered for any plant or department, and should perhaps have been more fully covered in the paper. The following features discussed should be emphasized and explained further:

From discussion by Mr. Zuelow: "In the case of general service departments the several functions are carefully analyzed and task standards established on all major controlling factors involved;....further and more scientific study into this subject is imperative if satisfactory and permanent improvements along these lines are to be properly guaranteed for the future."

From discussion by Mr. Jones: "The difficulty of preparing incentive plans for service-department employees should gradually be lessened as tasks tend to be standardized....There might be developed some possible interconnection between group-incentive plans and the total company profits in the lean years."

From discussion by Mr. Hecht: "The incentive plan at South Philadelphia is not confined to the service departments, but applies also to the supervisors and foremen of the so-called productive or operating departments....While past performances over several years were taken as a basis practically all expense accounts were modified before bonus earnings could begin. Some of the expense items were increased and others decreased. The standard expense allowance at Newport News is determined by either the total labor cost of the department or the total direct labor payroll. At South Philadelphia [due to 35 to 40 per cent of the operations being on an overtime basis] productive hours were set up as the determining base."

From discussion by Mr. Dildine: "It is evident that the continued future success of the plan must depend pretty largely upon the confidence of the employees in the management."

From discussion by Mr. Keller: "The service departments should first be studied to determine: (1) Essential and non-essential functions, (2) the man-power required to carry on the necessary functions, and (3) the responsibility for service expenses should be fixed on the department originating the expenditure....The complete study of the expense should be made on the basis of the requirements when one plant is producing on an average basis....The result is a standard manufacturing burden cost."

In the large plant under discussion in the paper, budgeting the expenses of all departments, both operating and service departments, had been in effect for two or three years prior to the introduction of wage incentives or bonus plans in the service departments. During this period, a close analysis and study of the functions of each service department was made, and the budgets revised, usually downward, until they were as fair and reasonable as could be predetermined at the time. These tasks or budgets were watched very closely by the heads of the respective departments as well as independently by the budget engineer, under the direction of the general manager. In addition to this, a special committee of seven members on "overhead reduction" was organized, and for two years prior to the group bonus plans described went into the details of organization and expenditures for each department in the plant. Through these means, the expenses were considerably reduced, in practically all departments, and the expense budgets, as finally revised before group bonuses were inaugurated were almost met or beaten for all departments. In other words, it took over two years to prepare the way for the group bonus plans described, and it would have been a great mistake to have put the bonus plans into effect first, then afterward to have made analytical studies, including time studies and the elimination of unnecessary functions. Perfection was not reached, of course, in setting the bogeys or budgets, and never can be, for that matter, for reasons brought out in the paper. The introduction of the bonus plans increased the interest, has sustained the interest, and has led to

many improvements through stimulated thinking that had not occurred to any one during the previous two or three years of preliminary study. The points brought out in the quoted discussions were recognized by the authors, when they said: "The present plans make it easier to go further and more scientifically into the whole matter."

For a plant working any considerable amount of overtime, like the Westinghouse plant at South Philadelphia, it is necessary for greater accuracy to use "man-hours" as the basis for output, rather than "number of employees in attendance," or "dollars of labor." Judgment must always be used in deciding between simplicity and accuracy. If all the records of a plant are kept in "man-hours," this should be the basis to use, in all cases.

Professor Lytle makes a good point of the method used of including the bonuses as part of the actual costs or expenses of the service departments, and then dividing the net savings equally between the employees and the company. Theoretically, it might be better to exclude the bonuses from the costs, for psychological reasons only, and then figure out the resulting division of "gains" as between the employees and company, say one-third to employees. In practice, however, this feature has never caused any trouble, as the plan was explained and agreed to in detail by the prospective participants in the beginning.

The important thing, after all, is mutual confidence between men and management. In the plant discussed, they have an "employees' representation plan" or "works council," through which all questions affecting the workers, hours of work, wages, incentive plans, piece rates, and earnings are freely discussed, with all data and facts known, which has made for confidence and a sense of fair dealing.

It will be noticed from a study of Fig. 3 that the budget line or "expense budget normal" is a straight line, instead of "drooping" as the actual cost line does; therefore as the output increases the bonus earnings increase more rapidly than the improvement in efficiency, corresponding to the idea of the Taylor differential piecework system. This feature makes the over-all success or profits of the company of great interest to bonus participants, since the total output (labor) or volume of sales makes for greater profits, other things being equal. This also takes care of the point raised by Mr. Jones, in an inverse manner, of paying larger relative bonuses when the company itself prospers greatly, and vice versa, paying very small bonuses in lean years. As to whether a company can "afford" to pay bonuses in lean years, however, that is a different matter; for if a wage-incentive plan of any kind does not assist in cost reduction and a better result for the company it should not be installed at all. This is important. If a company is losing money, as the large company discussed in the paper was, three years ago, then is the time to consider bonus plans, in order to put the company in a position to make money.

It should be remembered that wage-incentive plans for operating departments are much easier to develop and install in a plant than similar plans for service departments. There are many reasons for this. Therefore the start or beginning should usually be with the operating departments, and in the plant discussed this was done, as mentioned in the paper, but the description was confined to the work in service departments. It is stated that "incentives were already in effect before service department bonuses were started, with excellent results, not only for productive or direct labor employees, but for practically all executives, major and minor, including foremen and gang bosses."

One other matter should be made clearer: The budget formula $B = K + Pn$ is merely the equation for the line representing the "expense budget normal," in which K is a hypothetical or unreal constant equal to the "stand-by" charges when the department is practically closed down. In practice, as brought out by Mr. Hecht, the expenses of a department at this "mythical zero" of operation are practically impossible of determination with any accuracy. The "actual" figure for K, if it could be determined, would probably be lower than the figure used in the empirical formula. The formula is really determined after the line for the "expense budget normal" is settled upon and drawn. Actual spots for various conditions of output, when the details of the expenditure are analyzed, month by month, show the actual "trend" of departmental expenses, as the volume fluctuates; that is, they determine the "slope in gradient," of the line $B = K + Pn$, or the value of the expression Pn, as well as the "approximate position," up or down on the chart, of this line. The final budget line being settled, the value K is then calculated.

MAN-52-6

The Training and Recruitment of Auto Mechanics Through Factory Sources

By WILLIAM F. RASCHE,[1] MILWAUKEE, WIS.

This paper treats of the selection and training of automobile mechanics through factory sources and outlines what the evolution in development of service facilities and service workers has been, what the present-day requirements are, what type of individual should be selected for training, and how a factory training school must be set up with respect to places of instruction, the preparation of a curriculum, the organization of instructional material, and the training and supervision of instructors.

THE evolutionary forces controlling American business are compelling industry to make changes to meet new business conditions. These forces undoubtedly are not wholly welcome to business leaders who are coerced by this evolution in business to make extra efforts to secure the same financial returns they received formerly with a lesser expenditure of energy and money. Sharp competition is forcing them to refine their methods and practices in order that a greater industrial efficiency may be attained.

The automobile industry is no exception to this new development. Evolutionary processes are as certainly at work in this industry as in others, and the captains of industry operating in this field are as hard put to guide their enterprises safely through economic storms as are those in other fields. The effect, so far as the public is concerned, has been beneficial for the users of motor vehicles, who are now buying better motor cars at lower prices and securing motor-car service not equaled in the past.

It is the service phase of this industry to which this paper is devoted. One need but consider what has transpired in the last few decades to appreciate fully the significance of the great interest that automobile manufacturers are taking today in motor-car servicing and the marked efforts they are making to improve their motor-car servicing facilities for the benefit of the users of the vehicles they manufacture.

The prevalent practice of a large part of the owners of cars to trade cars in after a season's driving had its origin to a certain extent in the earlier unhappy experiences of automobile users who found it well-nigh impossible to have their cars satisfactorily repaired when mechanical difficulties developed in their cars and that required attention. A certain traditional overhang still exists which influences a large part of the present-day car users to have little faith in the integrity of the average automobile garage mechanic. They firmly believe that the safest way to avoid unsatisfactory treatment is to trade in their cars before the services of an automobile mechanic may be required. Indeed, one does not need to look far to find many car owners who will say that a trip to a garage to have a repair made is usually merely the beginning of a whole series of other motor-car troubles which seem to follow promptly whenever a car has made its initial trip to the service garage.

Much of the blame for malpractice in the auto-mechanics field unquestionably belongs to the blacksmiths and horseshoers of an earlier day whose occupational life was disturbed and finally dislocated as the automobile grew in popular favor as a means of transportation. These men, for the most part, were compelled to seek new occupational outlets, and many of them turned their smithies into garages and announced to the somewhat helpless traveling public their readiness to repair cars that needed repairing.

Automobile owners and users received at their hands what one would expect to be the case under such circumstances—namely, poor service at a costly price. These novices, like others who pick up new trades on the job, were experimenting at the expense of the public, in this case the car owners and car user.

Naturally, while a generation of blacksmiths was thus serving its apprenticeship in an adopted occupation, a car-using public had its difficulties in securing the kind of repair service it wanted, and looked for a means of escape. In this early unhappy situation automobile salesmen found a new market for new cars by inducing car owners to buy new cars on a trade-in basis, and thereby passed on to other people also desirous of owning cars, but possessed of smaller pocketbooks, the repair problems from which the more financially able buyers of cars sought to be relieved.

But even the used-car trade could not be long imposed upon. The ever-increasing number of car users, as well as the ever-increasing number of new and used cars on the market, hastened a public demand for more and better service facilities and more honest treatment. Manufacturers soon realized that the public was looking to them for protection, and they therefore gave attention to the problem of providing dependable and honestly priced service to the public. Manufacturers saw the need of announcing standardized prices for both labor and materials required in car servicing in order that the public might know just what it could expect to pay. Furthermore, appreciating that car users wanted some assurance that they were not placing themselves in the hands of unscrupulous or incompetent people, manufacturers selected with considerable care honest and competent persons capable of meeting the public needs and demands. To those who could thus qualify, manufacturers gave their approval, and approved service stations were designated through the use of the term "authorized service."

Early Improvements in the Service Field

But automobile manufacturers have learned that the selection of properly trained people for these responsibilities is no easy task. They found that there was no ready-made group of trained mechanics available to send out to render the service that the public demanded. They directed their efforts, therefore, to the training of experts who could be sent to branches and dealers to set up service facilities and to train out in the field men of potential ability in the proper servicing of the particular types of cars their employers manufactured. This movement was a step forward, and it put service work upon a better and more satisfactory basis than had been the case before. However, it resulted merely in the training of auto mechanics as such, men capable of doing the mechanical work required in service stations. It was

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Contributed by the Committee on Education and Training and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

a strictly vocational development in a special mechanical field and did not go beyond that. It had not reached the level on which service training must be done under present-day conditions, which require, in order that the demands of an exacting public may be met squarely, that the auto mechanic be in fact a mechanic plus, in which the plus stands for a number of additional qualifications that were not sought for especially in the earlier attempts at selection. It is indeed a far cry from the early "blacksmith made over into an auto mechanic" type of service man to the present-day efficient individual who greets the customer who is willing to accept the up-to-date authorized service of the better service stations.

The Selection of Trainees

At this point it may well be asked what, beyond the ability to repair cars, is required of those who would serve the public as competent automobile mechanics.

Field contacts made by the author with service-garage proprietors of reputable standing in various communities and his contacts with the service division of a large truck, cab, and coach manufacturing corporation, as well as observation of the educational practices of several technical and vocational schools which train service men and automobile mechanics, have led to the conclusion that the ideal automobile mechanic and service man should possess as a minimum the following qualifications:

1 All the necessary personal traits which attract instead of repel customers.

2 Thorough knowledge of the construction and functions of the makes of vehicles and their parts which he claims to be able to service or repair.

3 Ability to make repairs properly with the requisite speed and to have cars in a fit condition to be used by customers when they are called for.

4 Ability to sense potential sales of parts and to recommend their purchase when such transactions would actually confer a service upon customers.

5 Ability to sense, from the condition in which cars are brought in for service, a driver's mistakes which tend to shorten the usefulness of cars.

6 Ability to instruct so as to be able to teach customers how they may use their cars more intelligently in order that car users may derive a greater service from the cars they operate.

7 Ability to tell whether car troubles are due to defective workmanship at the factory, defective materials, or abuses for which the customers are responsible.

8 Enthusiasm for the product his employer sells and familiarity with the general policies of the manufacturer who builds the product.

Obviously, a mere mechanic, even if he knows all about repairing a vehicle, does not meet present-day requirements entirely, and those seeking timber for training must look for something in addition if the individual to be selected is to qualify in an all-round way. He must be a person of pleasing personality and must possess those qualities characteristic of a good salesman as well as those of the expert mechanic.

This wider range of qualifications adds to the difficulties of selection and recruitment. It is surprising how many people unsuited for the work seek to enter the auto mechanic's field. Many auto mechanics are selected by the dealers and service stations who need them, although it is questionable whether such chance selection in the field may be considered scientific. The one advantage which selection in the field has over selection at the factory is perhaps a lower turnover in service, because the selected individual usually has his home interests in the community where his services will be required. On the other hand, selection at the manufacturer's plant, through scientific selection through an efficient personnel division, is likely to insure a much better type of trainee.

Most large manufacturers now conduct service schools, either at their plants or at service training centers, in cooperating engineering schools where engineers also are trained. If their personnel divisions have set up scientific methods of selection in their employment departments, potentially good material for training will be secured.

An effective formula for selecting suitable trainees will result in the selection of:

1 Young men possessing average or above average mental ability who are eager to learn.

2 Men whose education is never less than that offered in a common school and preferably those who have had high-school training or its equivalent.

3 Vigorous men of good health who are physically capable of doing any task connected with the service repair work on an automobile.

4 Men of mechanical aptitude.

5 Men of good character with pleasing personalities.

Mental ability can be determined roughly by noticing the relationship between school age and school achievement as indicated by the scholastic record of the candidate. It can also be tested with mental tests, of which there are many kinds now on the market. Many of the more reliable tests have been used by various industries as well as schools.

School achievement is a matter of record and should always be considered, since it indicates how diligent the candidate was at the time he attended school. Training in physics, chemistry, and mathematics is a very desirable element in the trainee's scholastic equipment.

Physical fitness is a matter to be determined through physical examinations. These should be done thoroughly in order that accepted trainees may be minus any defects which will operate against their success in the occupation.

Mechanical ability is best tested by trial in the factory shops, especially in the manufacturing, assembly, electrical, and testing departments.

Personal characteristics are a matter for investigation. Inquiry should be made concerning the candidate's ability to get along well with others, his character traits, and his general standing in the community. Disinterested parties who know him should be consulted when securing this information.

This information should be supplemented, however, by further information secured from department executives who control the activities of the trainee while he is in their departments, in order that the statements of those who were given as references may be verified.

High-school councilors or vocational guidance officers in public-school systems are often prepared through their records to supply data which will give rather complete information concerning personal traits, especially any that show leadership qualities, aggressiveness, resourcefulness, and initiative.

The Factory Training School

A factory training school to be successful must have (1) a satisfactory place of instruction, (2) an appropriate curriculum, (3) properly prepared instructional materials, and (4) competent teachers. In addition there must be a functioning administrative plan to insure a high quality of instruction and the proper routing of the trainees. Furthermore, a direct contact must be maintained with the field in order that curriculum revisions may be made in the light of field experiences that are acquired in connection with the release of new car models.

The Places of Instruction

The places of instruction in an effective training set-up will be of two kinds. First, there will be the regular shop departments to which trainees will be assigned to tasks on the job, and second, a special demonstration classroom equipped with illustrative materials, models, and other necessary equipment.

The special demonstration room in such an arrangement should be exclusively in the control of the person who is in charge of the instruction, and in this respect it differs from the shop departments to which trainees are assigned. Because the primary purpose of shop departments is to turn out productive work, there is always great danger that foreman or sub-foremen, under the pressure of the demands of a production schedule, will tend to neglect the instructional work whenever they become hard pressed. Under the pressure of heavy schedules they are very likely to assign trainees to jobs that happen to be immediately available, but which are not always the kinds of jobs which serve instructional purposes best. For this reason the one in charge of the educational work must make a careful analysis of everything that is going on in the various departments and designate what jobs are to be done in the production departments, at what locations the trainees are to do their work, and under what conditions. This should never be left to chance, but should be specified in a typed or printed schedule which may be consulted by the executives in charge of the departments to which trainees report so that they may always know exactly what is expected of them. When such written guides are available, the administration of the educational work under the control of department foremen or subformen becomes much easier and very much more effective than when assignments are left to department heads exclusively.

In order that there may be a minimum loss of time for executives, instructors, and trainees, it is also well to have a floor plan of the shop departments on which are indicated the assignment locations. On this plan should also appear such symbols as will indicate what the sequence of travel through the department is to be. When such graphic guides accompany the typed or printed schedules, the administration of the shop instruction program will not be difficult.

Demonstration Equipment

Some things should be said concerning the special demonstration classroom. This should not be any old place in the plant, but one where good facilities for ventilation, light, and heat exist. It should also be located in a place where it is close to the operating departments to which trainees must go to do their practical work.

In the demonstration room there should be models of the many items that go into the construction of a car. These should be set up in such a way that the group to be instructed may see readily the underlying principles of operation of the various practical units with which they are concerned in the shop departments of the plant and with which they must deal later when they are employed at service work in the field. This classroom should also be very liberally supplied with good diagrams and graphic charts of everything that is placed in the motor vehicle. The supply of graphic-chart material should be extensive enough to present to trainees not only the mechanical and electrical arrangements of the current models, but also the differences existing between the latest and earlier models. Diagrammatic and chart material should also be supplemented with slides and films which can make the visual instruction more effective.

This classroom should further be supplied with a library of technical books which serve as source materials for trainees to consult in the hours when they are away from the plant and even during the study periods while they are at the plant. Those in charge of the instruction should be alert to the release of new technical books in order that this library may be constantly kept up to date. Naturally, the library should also contain trade catalogs of manufacturers whose products are used in the car made at the plant where the instruction is given. In addition to this, the manufacturer's own trade catalog, parts books, instruction manuals, and other practical literature should be made available.

It is needless to say that in addition to these items suitable furniture consisting of tables and comfortable chairs (but not too comfortable) should be provided.

The Curriculum

In any type of school the efforts of the teaching staff must be based upon a properly conceived and developed curriculum. This holds equally true for factory schools training people for service work.

Several factors must be kept in mind in setting up the proper curriculum. It is essential, first, that an analysis be made of everything that is built into the product of the manufacturer. This is nothing other than an inventory of all the tools, materials, skills, and knowledges that are employed in producing and repairing motor cars. A thoroughly competent service man must have mastery of all these elements before he can function effectively in the field at service work. The cue for making such an inventory can be secured from the parts books, instruction manuals, and other literature which the engineering division prepares from time to time as new models of cars are released.

The second factor which is not so easily determined consists in cataloging all the principal difficulties that the users of the product are meeting under actual transportation conditions throughout the territories where the product is used. The experience of manufacturers has been that the difficulties which are experienced with various types of cars do not run with the same frequency for all types. In one kind of model difficulties seem to localize in places entirely different from those which apply to other models, and so it is necessary following the release of each new model to keep closely in touch with car users in order to determine what kind of difficulties are developing for which a peculiar type of service may be required. This calls for the analysis of a stream of letters which come to the home office from branches, dealers, and service stations. These letters should be analyzed not only by the engineering and manufacturing divisions of the corporation, but also by the service school in order that service people may get the specific kind of training which will make them competent to cope with these difficulties. Because of this variation in the types of difficulties from year to year, some corporations are quite convinced that an annual return trip to the service school by field service men is highly desirable in order that they may get the additional training necessary to bring them up to date.

Instructional Materials

After an analysis has been made of all the specific elements concerning which a service man must receive instruction, it is important that these elements be organized into an outline of instruction and put into an instructional sequence that is the most effective for the learner to follow in acquiring the knowledge and ability which he must possess before he can function as a service man. Experience has shown that the logical sequence is not always the best sequence for instructional purposes. Good teaching calls for a proper psychological development of an outline of instruction. Rarely, if ever, do logical and psychological sequences coincide. Because they differ more often than not, it is incumbent upon the instructor who prepares the outline of instruction to place the elements to be taught in such a sequence as will insure the easy transition from one element to the next.

Stated in other words, this means that a competent instructor always recognizes the learning difficulties that are bound up with the various things to be learned. When the instructor keeps this principle in mind, he is naturally facilitating ease of learning, but must be sure that in the total range of instructional elements offered all the vital elements have been incorporated into the outline of instruction. This building of a proper outline of instruction is just as important as is the original analysis in which all the elements are inventoried irrespective of their significance in an instruction scheme.

Units of Instruction

Following the preparation of an outline of instruction it is necessary to prepare the individual units of instruction in which are presented informational matter, illustrations, type solutions, and problems. These individual units should be prepared in mimeographed form or printed for distribution to the trainees. Each unit should contain at the beginning a statement of objectives so that the student may know exactly what it is that he is to do. Following this statement of objectives there should appear a paragraph or two giving such general information as may be necessary to orient the student with respect to the type of work treated in the unit. Following this should appear a set of specific directions if it is instruction bearing upon learning how to do some type of service work or a discussion of the specific work if it is related information that is to be acquired. No unit instruction sheet is complete unless it presents to the learner specific problems to be solved by him. While it is perfectly proper to introduce specific information in units of instruction, and even to present the exact order for doing things, it is essential that as much opportunity be given to the student to do original thinking as it is possible to incorporate into the course, for his success in the work will depend very largely upon his power to analyze for himself typical motor car problems such as come into service stations for correction. It is good practice in the beginning units of any series to make the informational set-up complete and then to lessen it somewhat with each of the succeeding units. This will afford the student a sufficient background of knowledge which is essential for any one who would do original thinking and also will furnish the challenge which must be present in the course if it is to be effective.

It will be noted, therefore, that the complete cycle in the preparation of instruction involves three steps—(1) the analysis of the field, (2) the organization of the outline of instruction, and (3) the preparation of the detailed units of instruction.

Training Service-School Teachers

While it is perfectly sound to get practical instruction in the regular shop departments of the plant, it is fallacious to assume that foremen and sub-foremen are by and large good instructors. The day will probably come when foreman training will have become general and when every department head will not only be a good supervisor and manager, but also an able instructor. That happy day has not yet arrived in industry, and for that reason extra precautions must be taken by the training department of an industrial plant whenever it is desired to utilize the services of production foremen and their assistants in the instruction of service students. This presupposes in the first place that the person selected to head the service school is himself not only a good teacher, but a good teacher trainer. He should be thoroughly familiar with the principles of learning and teaching and must be in a position to give the foremen and sub-foremen of shop departments practical instruction which will enable these men to do effective teaching work with such men as are assigned to them for training. When such department executives do not have this preparation, it is important that arrangements be made to bring these men into training in order that they may acquire the teaching ability and technique which are essential for successful work. The head of the service school may very well prepare a series of lessons which will treat specifically of the learning-teaching problem. He ought to supplement his class work with mimeographed instructional material and a bibliography on education suitable for industrial work so that enterprising foremen and their assistants may make supplementary outside preparation for this work.

The Teaching Task

Many people in teaching positions think they are teaching when as a matter of fact they are not. Meeting groups of learners or talking and lecturing to them is not teaching. Telling and teaching are never identical. Telling may or may not be a part of teaching, but can never take the place of it. Granted that the trainees are people who have capacity to learn in the field in which they are seeking instruction, it is safe to assume that "the teacher has not taught until the student has learned." Just as it is possible to measure the products which are turned out by a production department, so too is it possible to measure the productive work of a teacher in a service school.

A competent instructor will be able to set up checking or testing devices in connection with every unit of instruction, as well as composite checking devices for a series of units, and if he is efficient, he will be constantly testing the progress of his class to make sure that each student in the class is securing just exactly what he should secure. If the testing work is thoroughly done in connection with any practical course of instruction in a service school, it will be possible to certify in a specific way what abilities the trainee possesses at the time when he finishes the course. In light of these facts no trainee should be released to the field who is unable to meet the minimum requirements that, by common agreement of those who are familiar with the work, should represent the fund of knowledge as well as the range of abilities required for successful field practice.

It may be said that whenever an outline of instruction is administered in this thorough way and it is known that there can be no certification until all the minimum requirements have been met, the trainees will get down to business at the very outset of their course of instruction.

Daily Schedule for the Students

It has been indicated that the student will spend his time between the shop departments and the demonstration classroom. There are various ways of dividing a student's work day. No arbitrary plan can be mapped out for this work, because conditions will vary with the varying requirements of different corporations. However, it may be said in general that at the beginning of the course of work probably considerable time should be given in the classroom building up the base so that students are furnished with an adequate background for their work. Since the work of a course will divide itself into a number of large blocks of instruction, it is good business to engage each block of instruction by spending sufficient time in the classroom to get the theory concerning it, and then to follow this with the practical work in that block of instruction in the appropriate shop department where the practical work is going on.

In order that students may have the opportunity to pool their daily experiences, it would be well to close each day with an hour of work in the classroom where the service instructor may check up with the students concerning their day's experiences, direct them to supplementary materials which they may need for outside study, and conduct such discussions as may be helpful. In this connection it may be said that it is good business to call in experts of the engineering, manufacturing, and service

divisions of the corporation and specialists from outside corporations which are suppliers for the corporation conducting the service school. In this way the students will secure a richer fund of knowledge than is possible when they depend entirely upon their experiences in the shop departments. In bringing in outside people to the school, either from other divisions of the corporation or from outside corporations, the head of the service school should attempt to secure people who are as nearly as possible good instructors as well as experts in their fields.

Length of Courses

The length of courses will vary depending upon the objectives to be served. Every company can afford to keep in training quite a number of men selected through the personnel division who will be kept in training from six to twelve months before they are ever released for service work in the field. If their instructional program is thoroughly organized, such men can be depended upon to fill rather important assignments provided the trainees at the time they begin training have all the potential qualifications given in the preceding list.

Every corporation service school, however, will have to deal with the short-term trainees who come in from the field for such periods as one day, one week, two weeks, and one month. The shorter the time available, the more abbreviated the instruction must be and the more important it becomes for the builder of the course of instruction to select those items for instruction which will be of most service to the people who are to be taught. People who come in for one day and one week are usually folks who are seeking to brush up on certain phases of the work concerning which they desire to have additional training. It will thus be noted that, in order to meet the varying requirements of the different types of learners to be served, the head of a service school must arrange his work so that it can be administered in the most flexible manner.

Personnel Records

Complete personnel information concerning factory-trained service men should be kept. These records should in the main give the usual personnel data found in complete employment office records, but in addition should cover three classifications of items to be entered as the learner progresses with his work.

The first classification should be a careful evaluation of the learner's personal traits, to be determined periodically by the various shop-department instructors and the head of the service school. Such traits as resourcefulness, initiative, industry, willingness to cooperate, and self-control should be carefully noted and recorded. However, before shop executives are asked to make such evaluations, they should be taught how to rate personal traits and characteristics.

The second classification should cover the learner's achievements with respect to his theoretical studies in the service classroom. The record covering this will indicate how well the learner can think and whether he understands underlying and related principles.

The third classification has to do with the learner's shop performances. The shop record should state how well the learner can diagnose motor-car troubles, how efficiently he can correct them, and with what dispatch.

The foregoing items when reliably gathered tend to correct the initial estimate of the learner secured at the time an investigation of his qualifications was made by those responsible for selecting trainees.

The foregoing discussion has treated of the training of auto mechanics through factory sources. The reader should keep in mind, however, that it is not possible to train all the men required for service work at factory schools nor even to select them there. The factory school can do only a part of what is required. The vocational schools throughout the land are in a splendid position to contribute also and their facilities and faculties should be utilized fully to meet local needs, for the solution of the service problem can be had only through using all the available agencies, of which factory schools are only one.

Summary

The organization of a modern service school for the training of auto mechanics through factory sources requires careful analysis of the work to be done, proper organization of the instructional material, the appropriate equipment of the shops and laboratories to be used for instruction, the selection of a highly qualified type of trainee possessing specific personal traits, business qualifications, and mechanical abilities, and instructors who are not only familiar with the subject matter of instruction, but who are well qualified to teach. No service school, if its work is to be done well, should ever certify trainees until through a system of checks it has been determined that they have met certain minimum standards and requirements to be agreed upon by those competent to set up such standards.

Discussion

Ray H. Sullivan.[2] There are several factors which have affected, now affect, and will affect the training and recruitment of auto mechanics through any source. A careful study of the problem discloses a few which are outstanding and which demand consideration in their solution, as follows:

1 The automobile industry's rapid growth.

2 Its geographically scattered application.

3 Mass production methods which practically revolutionized all industry and which eliminated factory labor for use as mechanics.

The writer believes that the leaders in the automobile industry wholeheartedly and sincerely welcome whatever may force them to refine their methods. They have always indicated both the desire and courage to attack and solve the multitude of problems which were incident to the tremendous expansion in the industry. He also believes that the industry is fortunate because in most communities, preceding the general use of the automobile, there was a mechanic who perhaps worked in a blacksmith shop and was at the same time a horseshoer and carriage maker. Certainly this type of more or less all-around mechanic filled what would have been decidedly a vacant space in the automobile industry. The very fact that he was more or less an all-around man was diametrically opposed to the mechanic in the automobile factory, due to the division of labor, and he was probably a life-saver to the industry.

Frequent and revolutionary experiments and changes were made by different automobile manufacturers which complicated the auto mechanic's job. Only some sort of versatile mechanic could possibly have spent the time and thought to do servicing of any type for a considerable period in the industry. The automobile industry has drawn liberally from this former blacksmith source, and some of its leaders today were trained in the fundamentals of mechanics through the hard school of experience as community blacksmiths. Consequently, many of these smiths were really forced to turn their shops into garages because of the public's insisting on some place to have their cars repaired, rather than the opposite.

We possibly are likely to stray too far from the advantages which came from knowledge gained from work applied on the job.

[2] Personnel Director, Fisher Body Corporation, Detroit, Mich. Mem. A.S.M.E.

By "on the job" is meant just as the work actually is presented by the customer, rather than any theoretical set-up.

The problem was and is really one of making almost instantly available the services of an unbelievable number of people scattered all over the world to repair and service products of the industry.

It does not seem, either, that one can reasonably charge the prevalent practice of changing cars annually to unfair treatment on the part of service men. Is there not a sort of natural desire on the part of every one to keep up to date—to get new things, whether it be clothes, radios, or automobiles? Is it not a good thing that the people in this country as a whole want those things which they own and use to be good looking? Regardless of servicing, a sufficient amount of use of an automobile will cause it to become shabby. It is believed that this factor, together with the desire to keep up with one's neighbors, played a large part in the purchase of new cars by people who were already in possession of cars which should give much more satisfactory service. It is also true that many people like to tinker with their own cars, and perhaps more damage is done by them than by almost any so-called service mechanic.

It would seem a tremendous waste of time and energy if each automobile manufacturer were to undertake the task of adequately training service men for their particular products in each village, town, or city in this country. Undoubtedly all automobile manufacturers, being progressive, will continue to have changes. To undertake the annual return of all automobile mechanics, who are actually in the field servicing popular makes, to the factory and the preparation of material designed to make them understand the technical questions involved as well as the practical would be a task requiring a tremendous investment without accomplishing the desired result. The use of the automobile is so widespread and its influence has been such that it is today a part of the duty of each community to provide the necessary facilities for what it is now believed can be standard auto mechanic instruction.

If the school systems would change their attitude somewhat, so that from the beginning youngsters were not impressed with the idea that the entire purpose of their school education is to fit them so that it will be unnecessary to work in the trades, it would be a big step in this direction. If, in addition to this, work on autos were introduced and available in our schools, the resulting mass effort would soon solve the problem.

The city of Detroit, in the Wilbur Wright High School, has what seems to be the right idea. Here, right on the job, standard makes of cars are brought in, overhauled, and repaired by the students, who at the same time are making themselves scholastically eligible for high-school diplomas. This school is operated on the cooperative plan. The student works two weeks in a garage, service station, or auto factory, and then spends two weeks in the school. The curriculum has been carefully worked out and provides as nearly as possible a connection between the theory taught in the classroom and the work in the plant.

Certainly there is room in the service end of the automobile industry for people in possession of all of the necessary personal traits for attracting instead of repelling customers. Certainly, also, the average percentage of people with these personal characteristics is present either in the blacksmith shop or other repair shop now handling the automobile service work. It would seem that the quickest solution would be to supply these existing service men the supplementary education necessary to develop these personal characteristics. To do this part of the educational job the automobile manufacturer must find some means for supplying these men with the knowledge and information which will be most helpful to them, whether it be along the lines of the development of personal characteristics or of the mechanics of their job. Undoubtedly some means for accomplishing this will be found. The writer believes that it will be along the lines of the present executive training extension work which is being applied to the executives in many of the leading automobile factories.

His thought, then, would be for the community to undertake and set up courses as part of their regular school work. These courses would be open to men selected by the educators and who had a knowledge of the requirements of the automobile industry. The curriculum could be set up in close contact with the industry generally. The industry would then be getting all of the things which the author has advocated, plus a much broader dissemination than would be possible in any single factory or even industry. The responsibility and work would be placed where they belong, in the hands of the educational organization in the community.

MAN-52-7

Summary of the Study of Technical Institutes

By W. E. WICKENDEN,[1] CLEVELAND, OHIO

THIS PAPER presents a highly condensed résumé of a study of a technical education above the secondary level, but of a more intensive and practical type than that offered by the four-year engineering college. The study has not included trade schools which train for skilled crafts, nor junior colleges which give the first half of a complete college course. Only terminal courses have been considered, and in general those which include in addition to technical subjects proper a substantial treatment of underlying sciences and drawing and usually some work in English and economics. The term technical institute appears to be the best common designation for the schools considered. Three rather distinct types of curricula fall within the area of the study: (1) Engineering courses which parallel the college courses in more intensive and practical forms; (2) courses in the technology of specific industries; and (3) courses preparing for particular technical functions. Some apprentice courses in industry are of a post-secondary character and include considerable formal instruction, but it has not been practicable to cover them in this study. Certain correspondence and extension courses have been included, though not comprehensively. Evening courses have been included, where the total ground covered is equivalent to a full academic year or more. In general, the study deals with an area of technical education, rather than a particular type of school.

The broader outlines of the study fell under three heads: (1) A study of typical technical institutes in the United States and of their personnel and courses; (2) a study of the needs of industry which can be met most acceptably through technical education of this character; and (3) a comparison of American and European technical education in this area. The third of these divisions has been presented to this Society in a previous paper and will be referred to but incidentally in the present instance.

Summary of Principal Conclusions

American industry, in practically all its branches, is understaffed with technically educated men; it must look increasingly to the schools rather than to the ranks for its technical and supervisory personnel. Its processes are becoming so specialized that experience, without special organization and supplementary instruction, is of diminishing value as training. Equipment and processes alike are growing constantly more technical, and there is a striking rise in the ratio of staff experts, of supervisors, and of technicians to the total forces employed. Meanwhile boys of superior ability are remaining longer in school—seven times as high a proportion attend high school as 30 years ago—and immigration restrictions have greatly cut down the influx of trained men from abroad.

The situation in industry should be met by a great expansion of higher technical education. Past efforts to meet similar needs have led to a great multiplication and expansion of engineering colleges, giving courses of four years and longer for degrees. Only this one phase of technical education has been adequately provided for in the United States. Greater efficiency demands that technical education should be diversified to meet a wider variety of individual and industrial needs. To maintain but one type of school is to invite blurring of aims and compromise of standards. Progress is in the direction of schools having more definite purposes and more clearly visualized aims.

The present group of engineering colleges, numbering close to 150 and graduating about 9000 men each year, do not provide adequately for the needs of industry. Engineering and sales staffs are fairly well recruited from this source; production and operating staffs most inadequately. Manufacturing industries estimate the desirable ratio of four-year engineering graduates to total forces at from 2.2 to 3.0 per cent. In a few industries this ratio of recruitment is being approached, while in others great deficits exist. Taken as a whole, this potential demand is about one-third supplied. The same industries estimate the desirable ratio of recruits from technical institutes, giving approximately two years of training above the secondary level, at from 6.0 to 8.3 per cent of the total forces. At present this potential demand is not more than one-fiftieth supplied, and an output of 25,000 to 30,000 graduates per year could be absorbed to great advantage. The estimates of relative needs by public-utility and transportation companies are of the same order, and there are grounds for believing that they fairly represent the mineral industries as well.

All the indications, both at home and abroad, point to the conclusion that the needs of the country can be best served by a great expansion in the area of the technical institutes, rather than by a further multiplication of engineering colleges. The colleges have developed around the idea of preparation for distinctly intellectual callings; the technical institutes aim principally at the higher forms of practical pursuits. The supervision of industrial production attracts the smallest proportion of college graduates, among the major functions of industry, and the largest proportion of graduates of technical institutes.

The technical institutes appear to cater more effectively than the engineering colleges to young men who have previously passed through a period of industrial experience and orientation, to men who have a career plan definitely mapped, to men who have passed out of a state of book-mindedness, to men whose natural learning processes center in actual doing rather than formal study, and to men who for financial or other reasons cannot devote four years or more to preparation for remunerative employment.

There is every reason to believe that enrolments in part-time and full-time day technical schools can be greatly increased. So far as total economic production is concerned the need for the labor of young persons is diminishing very rapidly. Great numbers are already partly or wholly free from the burden of self-support until the age of 21. The bent toward technical pursuits normally asserts itself between the ages of 16 and 19, and if higher technical education, in practical as well as theoretical forms, is made widely available locally, great numbers can be attracted to it.

Experience both in America and abroad indicates definitely that the more intensive and practical forms of higher technical education may be expected to achieve permanency and a large success only in institutions which have their own distinctive field and character. Attempts to do this work in auxiliary departments or in short courses of regular engineering colleges have

[1] President, Case School of Applied Science.

Contributed by the Committee on Education and Training for the Industries and presented at the Annual Meeting, New York, N. Y., Dec. 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

usually failed. There is as yet no basis in experience for expecting it to succeed in so-called junior colleges, especially those of a mixed character. The junior college is, in reality, an extension of secondary education and its curriculum a truncated college course. The technical institute needs the direction of men intimately in touch with industry and especially proficient in technical education.

Evening technical institutes constitute a strong second line of resources, though one of marked limitations. The full-time day school can ordinarily maintain a rate of progress from four to six times that of the evening school, and the half-time day school on a virtually all-year basis a rate two and one-half to four times that of the evening school. In a few instances evening schools considerably narrow these ratios by careful selection of students and exceptionally intensive work. It is difficult to maintain an efficient staff for evening instruction, unless the school is an auxiliary to a day school or a large industrial establishment. Correspondence and extension courses under private or university auspices are highly valuable expedients where established educational facilities are deficient. A vast field would remain to these agencies, even though a strong technical institute should be established in every industrial center of 50,000 or more inhabitants.

The cooperative plan, based on alternating periods of school work and industrial employment, appears to be particularly well adapted to the aims and levels of work of the technical institutes. This plan eases the economic burden on the school and the student alike. It affords the student a valid trial of aptitude and a normal orientation to industry, without necessitating a break in the continuity of education. This plan seems especially well adapted to the training of supervisory personnel, men who begin in overalls and climb the ladder which rises through foremanship to superintendency, and ultimately to management. It should be pointed out, however, that the cooperative plan does not obviate in any large degree the need for extensive scientific and technical equipment. The demands on equipment in a technical institute are, in fact, fully as intensive as in the engineering college.

The major geographical field of the technical institutes is at present in the dominantly industrial area east of the Mississippi and north of the Ohio and Potomac rivers. There is little immediate prospects of a local demand for schools of this character in the dominantly agricultural areas. It seems probable that institutes of a monotechnic type could be sustained successfully in the more intensively developed mining areas. The place of the independent endowed technical institute resembles that of the endowed college or university in many respects. It has been almost a rule in American experience that private initiative has been quicker to recognize neglected areas of education and to occupy them with pioneer institutions than have the public authorities. At a later stage, when the need has been advertised and examples of successful effort have gained some prominence, the public steps in and provides for the greater part of the need. The independent schools are still able to capitalize their freedom for experimentation with curricula, teaching methods, and selective standards of admission and to uphold an ideal of special excellence rather than large enrolments.

The private proprietary institution has been able to maintain itself in this field, because of otherwise unsatisfied demands, and in certain instances has rendered an admirable service at an economical cost. Doubtless there will always be a place for highly distinctive schools of this character. Welfare organizations have also entered the field, with the aim of serving men not provided for by other educational agencies. As a rule, these organizations have been under the necessity of making their educational activities pay their way in full, and the limited resources and equipment have left room for doubt as to the quality and permanence of their work, once the public awakens to its responsibility. A number of corporation schools which serve as means of selective recruitment and training for special types of personnel have gained an apparently permanent status.

The actual needs and potential demands, however, are beyond the resources of voluntary or private agencies. The situation seems to call for a great chain of community institutions, with their organic place in city and state educational systems. The author's view is that these schools should have a distinct character and a definitely technical program of work and that they should be set apart from the present system of comprehensive secondary schools and junior colleges. These institutions would provide both day and evening instruction. The author sees no necessity for limiting it to the field of post-secondary education which is the subject of the present study; secondary courses, with well-defined technical objectives, might well be included, as well as short unit courses for men with more limited needs. There are, in fact, a number of technical high schools for boys, which could be extended so as to do effective work in the post-secondary field and in real liaison with industry.

It would not be practicable to establish municipal technical institutes in the smaller cities. If this gap is to be well filled, it must be done by the states. The state, it would seem, should take the responsibility for training men for the more decentralized vocations, such as horology, which would only rarely fall within the scope of city institutions. The author believes that the largest field to be served is that of training in the technology of industries rather than that of generalized engineering courses. The former is largely neglected by the colleges and the latter widely and fairly adequately covered. This estimate of relative needs, however, does not reflect upon the effectiveness of the engineering courses of the technical institutes, some of which are of great excellence. The textile school, the foundry school, the machine production school, the building construction school, the printing and engraving school, and the leather industries school, however, are types in great need of multiplication.

Typical Schools and Programs

The technical institutes have such a high degree of individuality that it is almost impossible to exhibit their salient features in a small compass. Two general types are represented in the accompanying tables, the first (Table 1) a group of six full-time schools of well-established character, and the second (Table 2) a group of schools giving only evening courses in the realm of this study.

All of the institutions listed in Table 1 are independent of public support, and all but the first two are well endowed. All provide scholarship aid for a limited number of deserving students and assist some others by loans or employment. None, however, have scholarships to assist their graduates in pursuing further studies. Bliss alone of this group has dormitories and a required residential system. All but the Chicago Technical College have alumni organizations. Pratt and Rochester report some influence from employers favoring a change to college degree courses, and four schools report similar pressure to a minor degree from graduates and faculty members. Graduates of four schools in the group express some desire for more advanced courses. There is little active demand for other courses comparable to those now given, but such courses would probably be welcomed if offered. The heads of four institutions believe that education of this character can be given best in separate institutions; four designate full-time day courses as the best plan; one head prefers cooperative day courses; and the others rank this plan as "fair" to "good." None of the group prefers a sequence of one-year unit courses.

TABLE 1 FULL-TIME AND COOPERATIVE TECHNICAL INSTITUTES

	Bliss Electrical School	Chicago Technical College	Ohio Mechanics Institute	Pratt Institute	Rochester Mechanics Institute	Wentworth Institute
Names of courses	Electrical engineering	Architecture; building construction; civil, electrical, and mechanical engineering	Industrial electrical, mechanical, and industrial engineering; cooperative power laundry course	Industrial mechanical, electrical, and chemical engineering	Cooperative electrical, mechanical, chemical	Machine construction; electrical construction; power plant; architectural construction; foundry
Length in years	1	2	2	2	3	2
Weeks attendance per year	32	36	36 (engineering) 21[b] (laundry)	36	19[b]	36
Hours attendance per week	35	36	32½	30		30
Hours home-work per week	15	20	12 to 15	21		15
Entrance Requirements:						
Minimum age	18	16	None	None	None	18
Education	Grammar school + experience; high school preferred	Grammar school; 2 years high school preferred	4 years of high school	4 years of high school except for mature entrants	4 years of high school or equivalent	4 years of high school
Industrial experience	Not required, but preferred	Not required, but preferred	Not required, but preferred	Flexible; at least 1 year preferred	None	Not required, 1 to 3 years preferred
Enrolment, February, 1928	340	232	78	448	327	282
Graduates, 1927–28	316	41	22	180	52	119
Students dropped, 1927–28	15	25	27	9%	56	41
Tuition per year	$800[a]	$290	$100	$159	$135	$100
Cost of instruction per student	400		$300	$400	$423	$400
Plant and equipment provided	Earnings	Rental and earnings	Gifts	Gifts	Gifts	Gifts

[a] Includes board. [b] Also equal period in practice.

TABLE 2 EVENING TECHNICAL INSTITUTES AND EXTENSION SCHOOLS

	Cleveland Y-Tech.	Newark Technical School	Westinghouse Technical School	Rutgers University Extension	Penn State College Extension
Names of courses	Mechanical, electrical, structural, and chemical junior college	Civil, architectural, mechanical, electrical, automotive, and chemical engineering	Engineering	Essentials of mechanical engineering	Engineering
Length in years	3	4	4	3	3
Weeks attendance per year	40	28	32	24 to 26	24
Hours attendance per week	9	10 to 13	9	5	5
Hours home-work per week	12	4	9	5	5
Entrance requirements:					
Minimum age	None	16	None	18	None
Education	High school	High school or special preparatory course	2 years high school minimum	1 year algebra and service or equivalent	8th grade
Industrial experience	No definite requirement; average 3 years	None required; 3 years preferred	None required; students are employees	None required	Not required; 1 year or more preferred
Enrolment, February, 1928	[a]	1440	272	104	592
Graduates, 1927–28	4[a]	100	32	7[a]	95
Students dropped, 1927–28	46	260	82	8[a]	121
Tuition per year	$126	$60	$52	$40–$45	$30
Cost of instruction per student		$80	$58	$60–$67	$44.40
Plant and equipment provided	Gifts and earnings	Public and gifts	Rental, earnings, and gifts	State	State

[a] Course newly established.

Of the schools referred to in Table 2, only Westinghouse has scholarships and relatively few of them. Scholarship aid is usually regarded as unnecessary for evening students, practically all of whom are employed. Newark alone has scholarships to aid graduates in pursuing further studies. All but Cleveland Y-Tech. have alumni organizations. Employers apparently exert no effort to have the courses changed to a degree basis, but graduates do to a minor degree in two institutions. Graduates frequently ask for opportunities to go on with more advanced and specialized courses. Demands for additional courses comparable to those now given are not active, but might be cultivated, in the opinion of the directors.

Students and Student Life

The technical institutes do not, as a rule, insist on graduation from a four-year high school as a basis for admission. The percentage of high-school graduates runs high, however, in the more efficient day schools, less in the established evening schools, and low in the extension evening schools. The range is from a maximum of 95 per cent in the first group to a minimum of 36 per cent in the third. While few technical institutes make a formal requirement of industrial experience before entrance, nearly all prefer it. The number of entrants having had such experience ranges from 43 per cent in a day textile school, as a minimum, to 95 per cent in an established evening school, as a maximum. In this respect the evening schools as a group rank highest, the extension schools second, and the day schools lowest, as might be expected. In general, however, the previous employment in a majority of cases appears not to have been of a highly technical nature. The median ages of student groups, by schools, range from 19 years and 8 months to 25 years and 2 months, with a general median of all groups of 21 years and 0 months. Evidently students on completing their studies are mature enough to take on responsibilities and not too old or too highly individualized to fit into producing organizations. Few students are sons of professional men; the largest group, or about one-half of the whole, are sons of industrial employees.

Information given by alumni indicates that fully two-thirds of the students enter the technical institutes with a specific field of work in view. The chief reasons for this preference are given as special ability (39 per cent), being employed at it (31 per cent), economic possibilities (16 per cent), and family or personal influences (11 per cent).

Evidence gathered from nearly 1350 students and 600 alumni of a group of eight schools makes it clear that certain well-defined influences govern the choice of a school and a course of study. These may be classified as given at the top of page 66.

The most significant inference, it seems, is that so large a proportion deliberately decide to seek further education and choose a school by its reputation and a program of work suited to their time and means. Personal guidance by parents and others is apparently a minor, though growing, factor. Data

Influences Which Govern the Choice of School and Course

	Alumni		Present students	
	Yes, %	No, %	Yes, %	No, %
Believing personally in this type of education	84	16	90	10
Reputation of the particular school	75	25	85	15
Personal realization of need from practical experience	71	29	77	23
Lack of means for a long course of study	71	29	63	37
Knowing or knowing of successful alumni	53	47	66	34
Suggestions of friends	49	51	61	39
Lack of time for a long course	50	50	51	49
Institution being near home	38	62	37	63
Advice of alumni	37	63	44	56
Incomplete preparation for college entrance	39	61	33	67
Desire of parents	21	79	35	65
Advice of teachers in previous schools	14	86	30	70
Recommendation of employer	14	86	23	77
Desire for a particular section of the country	13	87	14	86
Advertisements of the school	14	86	11	89
Solicitation by person or correspondence	6	94	12	88

gathered from students in eight additional institutions corroborate these findings quite consistently.

Many other facts, gathered chiefly from alumni, throw light on student life and experience. Most of the technical institutes cultivate an active student life through athletics, clubs, social activities, and the like, though on a less elaborate scale than in the colleges. Participation in these activities appears to be quite general, 44 per cent of those replying specifying athletics, 36 per cent clubs and societies, 31 per cent school or class organizations, 16 per cent publications, and only 19 per cent no extra-curricular activities. The proportion who paid a considerable part of their own way is fairly striking: Earning no part, 17 per cent; to one-quarter, 16 per cent; from one-quarter to one-half, 14 per cent; from one-half to three-quarters, 11 per cent; from three-quarters to all, 42 per cent. Of those earning part or all of their own way, 32 per cent did so before entrance, 25 per cent in summer, 24 per cent during the school year, 17 per cent borrowed funds, and 2 per cent dropped out and later returned. This large measure of self-support doubtless accounts for the independent choices of schools and courses and contributes to the earnest, eager spirit so generally manifested by the student bodies.

Teachers and Teaching

Ten institutions were studied under this head. It is evident from the data that formal academic qualifications are not the primary criterion in the choice of teachers. One-fifth of the entire group of teachers are not high-school graduates, but every teacher has had training beyond the high school; more than 70 per cent of the teachers have had four years or more of such training and 18 per cent have had one year or more of post-graduate university work. The emphasis on the college degree varies widely. In one of the most efficient schools 12 of the 14 instructors do not hold degrees, but are graduates of the school itself. On the other hand all the instructors in two of the ten schools hold degrees. In general a considerable number of the teachers are themselves the product of some form of adult education.

While formal academic credentials are not highly emphasized, great weight is given to active industrial experience. Fully 97 per cent of the teachers reporting have had a year or more of non-teaching experience, obtained in most cases before entering their present work. Of this number more than half have had five years or more of experience in practice. Many teachers in evening and extension schools are in active practice in their professions, while those in full-time schools usually maintain a fair degree of collateral practice. Over 60 per cent of the teachers are enrolled in one or more professional societies. The amount of original productive work is considerable, more than one-quarter of the teachers having publications to their credit and one-fifth having made one or more inventions.

One-quarter of the teachers are under 30 years of age and less than one-tenth are above 50 years. The median age is close to 35 and the median period of teaching experience is about 7.5 years. Lack of common units or comparable conditions makes it difficult to give an accurate picture of teaching loads. In general, the loads in full-time schools run higher in clock hours than in the colleges; namely, from 18 to 35 per week. Class sections are frequently fairly large, numbering from 35 to 40 men, and laboratory, drawing, and shop sections from 15 to 25 men. Where both day and evening classes are held, teachers commonly have part of their work in each division.

The subjects taught by one instructor are along closely related departmental lines, as a rule. The coordination between departments or individuals varies even more widely than in the colleges. Wherever a highly distinctive course has been developed, the work of individual instructors is close-knit; at the other extreme instructors confess to being "uncertain" of their responsibilities and go by their own judgment as long as no one objects. In a few schools the materials of teaching are closely scrutinized by a committee of the faculty, and cooperation between departments is secured by frequent conferences. Special manuals of instruction, prepared by the local staff, are used in the majority of classes. Local needs are usually conceived to be unique; frequent comment that "no published material suits our situation" is met. A bare beginning has been made in providing published texts with this field of teaching in view. When one considers the stereotyping influence of the textbook in the engineering colleges, he hopes that the technical institutes may be able to maintain conditions that favor greater originality and flexibility. On the other hand, the present lack of prepared teaching materials undoubtedly tends to check the spread of the much-needed types of schools and courses.

Teaching methods in the technical institutes do not depart widely from accepted practices. In general, however, the theoretical phases are greatly condensed and the practical phases more heavily stressed. Some teachers state that they test and grade their pupils by their ability to make practical applications of their studies. It appears that in many cases a higher proportion of the student's work is done in scheduled hours under supervision than in more academic types of schools; nearly half the teachers, in fact, report that from two-thirds to all of their work is of this type. The assigned work to be done outside, as a rule, consists less of text material than of problems and exercises. Nearly half of the teachers report basing less than one-third of their assignments on text materials. While it is not explicitly stated in any of the reports, it appears that the technical institutes cater to "learners" rather than "students."

No great originality of method has been observed. One institution emphasizes that fact that the practical work given in the first year is a foundation for the theoretical work of the second; another that its teaching matter is selected in the light of job analysis; while in two cases the courses are divided into well-defined units, with practical exercises closely paralleling the text material to enable students to enter at any time, progress at an individual pace, leave when they wish, and resume the program at any point. In general, the lecture is but little favored. Conferences and recitations, with active participation, make up the greater part of the classroom activity. Drawing, shop, and laboratory exercises are largely stressed. In textile schools the instruction matters are very specific, all general studies being eliminated. The heads of all schools agree in emphasizing the practical qualities of their instruction, pointed directly to employment objectives and dealing with specific problems which their graduates will meet in industrial work. There is little tangible evidence, however, that practical performance is given great weight in grading their classroom performance. Aside from two schools with cooperative courses,

only one makes industrial experience a definite prerequisite for admission or for graduation.

The off-campus teaching of the state college extension divisions, as observed, was distinctly below that of the regularly organized technical institutes in efficiency. The classes were less homogeneous in ability and preparation; practical equipment was almost wholly lacking; and teaching is apparently a "pick-up" task for part-time men without training in educational methods and with little time for planning and preparation. The extension enterprise, while of undoubted value where other facilities are lacking, appears to have many of the qualities of a business, to be expended with only minor concern for admission standards, vocational selection, teaching efficiency, and the like. It is possible that these efforts may actually retard rather than advance efficient state-wide programs of technical education of a non-college type, in order to preempt financial support and control for the benefit of a state college or university.

In the matter of teaching salaries no common basis exists for a comparison of full-time and part-time staffs. Data covering three full-time staffs exemplifying the best standards cover a range of individual salaries from $1900 to $6000 per annum with medians of $3600, $3100, and $3000, respectively. The rates for evening teaching alone are in some cases proportionate to these scales, but in most cases very much less. In fact much evening teaching is plainly a means of earning extra income adopted by low-salaried men in practice, though some notably successful teachers are to be found in this group. But one individual reported a normal salary in excess of $5000, and the modal group lies between $2500 and $3500. Data on earned incomes from outside practice for the three full-time staffs cited show a range of from nothing to $10,000 per year. Apparently about half of the combined groups enjoy an appreciable supplementary income, although most schools encourage a reasonable amount of outside work.

Speaking out of their own experience, the teachers emphasize the following as their most important qualifications, in the order stated:

(1) Knowledge of the subject
(2) Experience in practice
(3) Ability to present the subject clearly
(4) Ability to inspire interest in the student
(5) Understanding of relations with industry
(6) Sympathetic insight into the student's individual problems.

The organization of the ten schools studied provides in general for greater centralization of authority than is common in college faculties. Only three of these faculties are organized, although all meet occasionally in an advisory capacity. The directors usually select the teachers. Few of them report exceptional difficulties in finding men, although one of the most discriminating directors reports that neither ex-college teachers nor mature men from industry, as a rule, have been found satisfactory. All but two of the schools draw from industry more than from other sources. Four definitely prefer their own alumni; the others in only a minority of their appointments.

Status of Graduates

It has been seen that chance is only a minor factor in the choice of a school and a course of study. The same is true of a choice of position after graduation. The main reasons assigned by graduates are as follows: Special interest, 35.8 per cent; special ability 8.7 per cent; future economic possibility, 10.2 per cent; present economic advantage, 6.5 per cent; geographic location, 6.9 per cent; family influence or connections, 6.4 per cent; only position available, 19.4 per cent; other reasons, 6.1 per cent. There is considerable shifting of employment in the first few years after graduation. Graduates of five technical institutes were studied and compared with graduates of engineering colleges. The variations among the five groups were not marked and the composite result is fairly representative.

Percentage of Graduates Holding Indicated Number of Positions in Certain Periods

	—Technical institutes—				Engineering colleges		
Number of Positions	One	Two	Three	Four	One	Two	Three
Period:							
6 months	91.2	7.8	1.0	...	79.7	20.3	...
18 months	57.3	30.1	11.6	1.0	60.5	26.5	13.0
30 months	25.7	46.6	20.8	6.9	43.0	32.0	25.0

In general there is a fairly close agreement between the fields of work of graduates and the courses of training pursued. Variations between schools are relatively small, and the composite result is therefore representative. Comparisons with engineering graduates are of interest.

Percentages of Graduates in Fields of Work as Related to Courses

	Same as course	Closely allied	Not closely allied
Technical institute	69.8	17.9	12.3
Engineering course	61.8	7.4	30.0

The closer relation in the former case sustains the view that men attend technical institutes with more definite aims in view than those of engineering college students. It is difficult, in small compass, to indicate the specific character of the positions held or the routes of progress along which graduates advance. The three largest groups are: (1) Supervisors (production, operation, maintenance, etc.), (2) engineering personnel, and (3) proprietors of businesses. About two-thirds are included under these heads.

Employers of graduates have listed the more outstanding traits or types of adaptability of technical institute graduates in the following order:

1 Adaptable to supervisory positions and advancement in operating departments
2 Adaptable to plant operation and maintenance
3 Ability to get on with workmen
4 Adaptable to technical services (drafting, designing, editing, testing, inspection, etc.)
5 Ability to do team work with associates
6 Ability to cooperate with executives
7 Adaptable to construction and erection in the field
8 Willingness to accept plant hours and conditions of work
9 Adaptable to technical sales work

The ratings of employers were equally divided between *yes* and *no* on the two items:

10 Adaptability to administrative or executive positions
11 Adaptability to technical forms of business, such as contracting

The opinions were distinctly negative on the two following items:

12 Adaptability to staff engineering positions
13 Reasonable expectations of advancement in salary and rank.

It should be noted, however, that considerable variations exist between schools in the rating of graduates. Graduates of one of the strongest schools, with a definite engineering emphasis, were rated as "better than average," tending toward "outstanding" on adaptability to staff engineering positions, and even higher on adaptability to technical sales work.

The earning power of graduates of the more thoroughly organized and efficient technical institutes parallels that of engineering college graduates of the same maturity. The differential

between the medians of the two groups is not large in any case, and scarcely any exists between the more carefully selected graduates of technical institutes and college graduates in general. As an illustration a comparison may be made between the medians of four groups: (1) Engineering college graduates in general; (2) four-year electrical engineering graduates of a somewhat selected character; (3) two-year electrical engineering graduates from one of the outstanding technical institutes; and (4) one-year electrical engineering graduates from a school of excellent quality:

Comparison of Median Earnings of Graduates

Years after graduation	0	2	4	10	15
Four-year graduates in general	$1500	$2100	$2600	$4000	$5000
Four-year graduates in electrical engineering	1500	1900	2460	4000	4850
Two-year graduates in electrical engineering	1450	1800	2450	3350	4700
One-year graduates in electrical engineering	1200	1600	2050	3100	4600

The institutes experience no difficulty in placing their graduates once the product is tried and known. The contacts with employers in nearby areas are usually close, and a few schools have made permanent contacts with employers in more distant sections. For example, one has a standing order from a large concern for five graduates each year, who are accepted without interview on the judgment of the officers of the school. Institutes operating on the cooperative plan have no employment problems of consequence, but experience a demand from their clientele greater than their supply.

Reactions of Graduates to Their Education

A valuable index to the effectiveness of a particular type of education is found in the reactions of graduates. The alumni of eight schools were questioned, and the results show only minor variations between institutions. The composite replies were as follows:

To what extent has the course met your expectations:	Good, %	Fair, %	Poor, %
(1) In satisfying the technical requirements of your job?	75.5	22.8	1.7
(2) In satisfying supervisory, managerial, or other requirements?	48.2	40.0	11.8
(3) In your earning capacity?	41.1	50.7	8.2
(4) In your general education?	52.3	40.3	7.4
	Yes, %	No, %	Blank, %
Have you felt the need or desire for further courses of study?	81.9	8.2	9.9
Have you had any extension or correspondence courses?	34.8	40.6	24.6

The reasons offered for needing further courses were as follows: Fuller general knowledge (36.1%), continuing more advanced work (28.6%), broader business knowledge (27.9%), making up deficiencies (3.9%), greater responsibility (3.5%).

The suggestions offered for changes in the technical institute courses may be ranked in the following order: English and public speaking (29.7%), more and higher mathematics (29.1%), commercial and business subjects (17.0), more science (13.3%), practical applications (4.9%), cultural subjects (3.6%), miscellaneous (2.4%). The desire for a broader and more fundamental education is clearly revealed.

The replies to the question as to whether graduates of technical institutes would do it over again are of special significance:

If you had it to do over again, would you:	Yes, %	No, %
Go to the same type of school?	88.9	11.1
Take the same course?	84.4	15.6
Go to another type of school, such as the four-year college?	80.1	19.9

The apparent inconsistency in the first and third items is easily explained by assuming that the words "under the same circumstances" are understood in the first case.

Testimony as to any tangible handicaps resulting from the absence of a college degree is as follows:

	Yes, %	No, %
(1) In obtaining employment?	20	80
(2) In obtaining advancement?	24	76
(3) In gaining recognition by professional and business organizations	29	71

There is apparent need of recognition or credentials of broader acceptance, but it seems clearly not to be in the form of meaningless degrees. The desire for degrees was manifested almost wholly by those recently graduated.

Technical Training Needs of Industry

Of all the evidence gathered that which deals with the requirements of industry is probably the most conclusive. The State of New Jersey was selected for an intensive study of the needs of industry for technically trained men. A number of reasons contributed to this choice, including the existence of considerable data, the diversity of industries, proximity to the base of studies, and familiarity of employers with the technical institute graduate. Three separate inquiries were made, with startingly consistent results.

Quotas of Graduates of Technical Institutes and Engineering College Graduates Preferred by 48 Manufacturing Companies[a]

Field of employment	Technical institute men	Four-year college men or beyond
Mechanical	817	316
Electrical	116	111
Civil engineering	6	18
Chemical	345	146
Mining	6	4
Miscellaneous	12	0
Total	1302	595
Ratio	2.8 to	1

[a] Data from survey of Rutgers University by U. S. Bureau of Education.

The second inquiry was made by the Dean of Engineering at Rutgers independently. Data came from 21 manufacturing companies, representing a wide range of industries.

Ratios of Technically Trained Graduates Desired by 21 Manufacturing Companies

	Four-year college	Technical institute	Manual and crafts
Percentage of total employees	2.2	6.0	14.8
Ratios	1 to	2.7 to	6.7

The third study was made by a large and comprehensive public utility organization covering the same area, in cooperation with the staff.

Ratio of Technical Institute Graduates to Four-Year College Men Desired by a Large Public Utility Organization

	Technical institute	Four-year college
Percentage of total employees	8.3	3.1
Ratio	2.7 to	1

A fourth study, made in California by Frank W. Thomas, quite independently, gave the number of positions in twelve corporations which were believed to require only two years of "college work" as 755, and the number believed to require four years of "college work" as 289, or a ratio of 2.6 to 1.

In order to check the results obtained from so local an area as New Jersey, an inquiry was made of 15 representative companies in 11 states which were believed to have had considerable experience with both college and technical institute graduates. It was found that 12 had had considerable experience as anticipated, two some experience, and one not enough to justify an expression. These companies were asked whether from their experience they felt that there was an area of terminal technical education, intermediate in duration between vocational and trade schools on the one hand and engineering colleges on the other, needing to be encouraged and developed in America. The replies were unanimous in the affirmative. The relative

importance of the aims of technical institute training, as indicated by the composite replies of these 15 companies, was as follows:

Aims of Technical Institute Education	Weights
(1) To qualify men for supervisory positions in operating departments	1.00
(2) To qualify for technical services such as drafting, designing, testing, inspection, etc	0.74
(3) To qualify for commercial positions relating to the sale of technical products and services	0.56

In reply to a query whether they would prefer men graduated from a *general* course covering a fairly wide field of study and intended to qualify men for a wide variety of work, or from a *specialized* course covering intensively a particular line, the result was seven in favor of the specialized course, five for the general, and the others non-committal. The value of both types was generally recognized.

Through the courtesy of the National Industrial Conference Board, data were obtained on the personnel of the more important technical and supervisory positions in 878 concerns employing 429,600 men in five major manufacturing industries. The distribution of the college-trained men in the major groups of positions or functions in these companies are as shown below:

Percentages of Technical and Supervisory Positions in Manufacturing Now Held by College Trained Men

Groups of positions	Chemical industry	Electrical manufacturing	Metal trades	Paper and pulp	Rubber industry	Total of the five industries
General officers	65.0	47.1	45.8	32.8	43.9	46.6
Engineering and technical	57.2	55.2	31.0	50.4	55.2	48.6
Production	17.6	10.3	5.6	10.4	9.4	9.3
Sales	23.4	58.7	24.5	15.3	19.3	38.4
Miscellaneous	11.6	19.1	7.7	9.5	23.5	13.8
For the industry	29.8	37.1	17.1	22.0	23.8	28.0

The relatively low recruitment of production officers from college sources cannot escape attention.

In the following tabulation a comparison is made of two groups of college graduates and of six groups of technical institute graduates with respect to functions in industry:

	Groups of positions				
	Miscellaneous, %	General officers, %	Engineering and technical, %	Sales and advertising, %	Production, %
College, 3199 non-engineering graduates	18.4	20.1	10.3	42.1	9.1
College, 11,895 engineering graduates	7.7	7.2	39.2	36.9	9.0
Lowell Textile Institute, 325 three-year graduates	23.1	22.5	20.0	10.1	24.3
Pratt Institute, 1176 two-year mechanical engineering	9.0	17.9	41.9	9.6	21.6
Pratt Institute, 656 two-year chemical engineering	5.5	17.2	42.7	9.0	25.6
Pratt Institute, 1187 two-year electrical engineering	7.8	11.9	40.6	9.3	30.4
Bliss Electrical School, 1398 one-year electrical	23.8	11.1	26.0	6.1	33.0
Wentworth Institute, 377 two-year various	15.7	4.8	32.3	8.7	38.5

Estimate of Total Potential Requirements

Estimates of the total potential requirements for technical institute training are likely to be conservative if one is concerned chiefly to guarantee a maximum individual opportunity to those so trained, or liberal if one is guided by the estimates of the personnel needs of employers. No data exist for estimates of the former type. As a basis for the latter, there is the expressed opinion of manufacturers and others covering the desired ratios of various types of trained personnel to total forces and to each other. Applying these ratios to the manufacturing industries of the country at large gives results as follows:

Total employees in manufacturing (1925)	9,857,697
Approximate technical institute graduates employed	10,000
Approximate total of technical institute graduates desired	591,462
Annual quota of technical institute graduates at 3 per cent	17,745
Annual quota of technical institute graduates at 5 per cent	29,573

If an estimate is made for the mineral extraction industries by assuming that like ratios may be applied to the salaried officers as to the technical and supervisory of the manufacturing industries, the result is as follows:

Total salaried officers in mineral extraction	96,115
Estimated number of college graduates needed	13,404
Estimated number of technical institute graduates needed	36,191
Estimated number from the ranks and otherwise trained	46,520
Annual quota of technical institute graduates at 3 per cent	1,086
Annual quota of technical institute graduates at 5 per cent	1,810

A study of the personnel needs in transportation and communication has indicated that a proportional total of technical institute graduates would be 100,000, or an annual quota of 3000 at 3 per cent or 5000 at 5 per cent. When additional allowances are made for other census classifications, such as agriculture, forestry, personal service, trade, professional service, and clerical occupations, the total annual quotas to maintain an optimum recruitment of industry, in its all-inclusive sense, work out at approximately 36,000 at 3 per cent of the total appropriate positions and 50,000 at 5 per cent of the total appropriate positions.

In fact, the potential fields for employment of technical institute graduates appear to be limited only by the sources and facilities to train them and the right kind of men to be trained.

Discussion

James A. Moyer.[2] This paper must necessarily be merely an abstract of the report of the committee which has been engaged with its experts during the last two years in a survey of the field of technical education as it relates to non-collegiate institutions. Much discussion has arisen as to nomenclature in defining the scope and in recording the results of the survey. The most suitable name for the type of institution to be surveyed was not easily decided. The committee is fairly well agreed, however, that the name non-collegiate is properly descriptive and suitable for the purposes in mind, and yet this name does not properly eliminate from consideration the ordinary vocational or trade school devoted to training of the apprentice grade.

During the period of its existence, the committee and its experts have been devoting much time and thought to the problem to finding out the real field of usefulness of the non-collegiate type of technical institute or school. Unfortunately, there has been a general impression among engineering teachers that there was no well-defined place among our educational institutions for this non-collegiate type. In fact, instructors in search of positions have often hesitated to accept teaching appointments in these institutions because of the unfortunate idea that their work could not be put on a sufficiently high plane. In other words, they did not realize the difference between the educational activity of the type of institution which is being discussed and the ordinary vocational or trade school which is usually supported by taxation.

It occurs frequently that educational institutions for technical training which were originally of the non-collegiate type are being gradually transformed into another more standardized kind, which is called the collegiate type. For more or less personal reasons in some cases the presidents and other executive officers of the non-collegiate type of institution have exerted forcibly their influence for the change, and the facilities of the institutions have invariably given encouragement for very much the same reasons that influenced the executive officers.

There is a striking case which comes to mind in the change from the non-collegiate to the collegiate type of institution in a city in the East. It happened that the institution was founded and

[2] Director, State Department of University Extension, Boston, Mass. Mem. A.S.M.E.

had for its first president a man who realized the important work which could be done by a non-collegiate type of institution, and who was not carried away from a well-defined purpose by a desire for collegiate degrees and academic distinctions. In later years, one of his successors managed to build up the collegiate type of faculty for the institution, and worked year in and year out with the active support of most of his faculty for a change to the collegiate type of institution. Finally, the trustees agreed to adopt his recommendations, and now there is one more collegiate type of technical institution almost within a stone's throw of another long-established and increasingly useful college of engineering. In this case, there is no doubt that the institution in which the change was made was needed much more in the non-collegiate than in the collegiate field. The difficulty was, however, that the president, the executive officers, and many of the faculty had personal ambitions to be satisfied. Frankly, they did not like being connected with an institution which did not have the highest collegiate standing. Personal academic distinction appeared to be a more important factor with these men than the usefulness of their institution to the community. It was for this reason that they influenced the trustees, with much hesitation on the part of many of them, to make the necessary changes in the admission requirements and in the curriculum, to make a place for the institution among those granting academic degrees and having collegiate standards.

One of the most important conclusions to be drawn from the survey is that the employing agencies of large industrial plants and organizations are able to state with considerable definiteness for what type of employment they prefer the graduate of the non-collegiate technical school. This is especially true in the field of production engineering, where the statistics seem to show that the graduates of the non-collegiate institution have the preference, and will probably be most successful. In fact, the opportunities in this branch of engineering seem to be especially advantageous for the graduates of the non-collegiate institutions. Financial rewards are not lacking for those who are engaged in production departments, and the prospects for advancement to superintendent or head of a department are excellent.

In general, the results of the survey will give renewed enthusiasm to the executive officers and faculties of the non-collegiate type of institution to continue their work in their present fields, and resist the tendency to drag their institution into the collegiate list.

S. S. Edmands.[3] An outstanding feature of this exceedingly valuable and noteworthy paper by an eminent student of higher technical and engineering education is the two-fold conclusion appearing therein; namely, (1) that American industry is understaffed with technically educated men, and (2) that the needs of the country may best be served, not by a further multiplication of engineering colleges, but rather by a great expansion of "technical institutes," an allied type of school to which a large and distinct field of serviceability is assigned. This conclusion is not that of the paper's author alone, but is one of a number of very significant findings in a recently ended comprehensive survey under the auspices of the Society for the Promotion of Engineering Education, with which investigation Doctor Wickenden was associated in the capacity of director.

The diagnosis that American industry is lacking in technically trained personnel will surprise no one conversant with the actual situation, but the prescription of many more trained men from the thus-far few, underdeveloped, and but little-known or understood technical institutes, rather than from the numerous and strong colleges of engineering, would seem quite absurd to the average person, were the pronouncement from almost any source other than the above-mentioned society, which is the foremost champion of the widespread and deservedly well-esteemed college form of technical education. The diagnosis and prescription reflect both the competent character of the investigation and the fairness and broadmindedness of its auspices. The finding is the more impressive because the society's membership is representative chiefly of the American college of engineering and its vast vested interests. However, the motive here should not be mistaken for mere altruism, inasmuch as one of the major conclusions of the society's investigations is that the welfare of the engineering college and the possibilities for continued betterment of its service hinge importantly upon the proper development at the same time of the neglected institute form of higher technical education. The investigations also bring out prominently the fact that no such disparity between the two types of education exists in any other large industrial country, and that the condition contrasts regrettably with the well-balanced systems of technical education maintained by the leading European nations.

This authoritative pronouncement that national lopsidedness in technical education needs correction brings timely reinforcement to the unfortunately few pioneer technical institutes. These have found themselves seriously handicapped in their efforts to make headway against a prevalent national indifference ascribable in part to the general over-emphasis upon the college form of education, and in part also to the long period of unparalleled industrial prosperity that has undoubtedly tended to distract attention from the importance of greater efficiency in American higher technical education. Doctor Wickenden's paper and the study which it so ably summarized should help greatly to stimulate a wider interest in technical education outside of the colleges through dissemination of reliable information regarding the need for and the various service possibilities of the "technical institute."

Walter B. Russell.[4] In presenting this paper the author has rendered a most valuable service both to education and industry. He has helped to crystallize the term "technical institute" as the most suitable name by which to designate schools of the type described. Few persons realize the importance of an appropriate title for any enterprise, especially for a school in a new field which must be clearly understood by people generally, and which, more than most endeavors, needs to have its aims and purposes clear and definite in the public mind. Consequently, one cannot overemphasize the value of this first contribution to the field of education in establishing the general recognition of the name of "technical institute." Clearly these schools were not colleges, nor universities, nor high schools, nor trade schools, nor manual-training schools. Too often in the past it has been necessary to describe them in negative terms, stating what they were not and calling them non-collegiate, non-standardized, etc. By placing emphasis on the name, "technical institute," the author gives these schools a definite place in the educational scheme of the United States. Both the schools and the many thousands of creditable graduates throughout the country welcome the change and rejoice in a new and recognized status.

The next outstanding feature of the study is in the tabulated results of the needs and the potential needs of industry. No one has heretofore known even approximately the extent of the needs of industry for men trained in short, intensive courses of specific character such as those offered by technical institutes. No one has attempted to list the rapidly increasing number of new positions which have developed in production and operating companies, or the range and variety of the new stations and func-

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[4] Director, Franklin Union, Boston, Mass. Mem. A.S.M.E.

tions of a supervisory nature which are best filled by men with the technical-institute point of view, the technical-institute orientation, and the technical-institute intensity and definiteness of training. Previous estimates that industry could absorb ten times the number at present graduated are dwarfed by the author's announcement that the potential demand of the industries for this type of graduate with this sort of training is not more than one-fiftieth supplied at the present time. The paper shows the increasing necessity and the general demand for great additions to the numbers of technically trained men who are needed if the industries are to keep pace with the rapid changes which are taking place in organization, in development of new processes, and in the multiplied scale of production.

The field from which the technical institutes draw their students is distinct and separate from that of other kinds of technical training. It is almost as large as the combined fields of all the other more familiar types of education put together. This is made evident by plotting on a chart that shows the population of the United States at each age level between the ages of 5 and 26 years a curve separating those persons who are in school from those out of school. There will be found twenty-five million persons between these ages in school, and almost as many, twenty-three million, over 14 years of age, outside of school. It is this group of twenty-three million between 14 and 26 years of age out of school in "No-Man's-Land" that constitutes the field from which the technical institutes draw their students. There is, therefore, no competition with the standardized or academic forms of training. It is this enormous group of out-of-school youth that must provide the bulk of the supervisors, inspectors, and minor executives so much needed by industry, and who are, according to the author, but one-fiftieth supplied. It is for this vast group of young people who are "off trail" that the technical institutes have established new avenues of training. For various reasons those in this area have left school, and cannot, if they would, get back again into step with the regular program of high school and college. Other trails must be provided if they are to climb in our present industrial life and development.

The technical institutes have but recently started. They are pioneers exploring a new field. The field is almost unlimited. It contains boys and men with an innumerable number of different needs and an endless variety of educational and industrial background. To meet just a few of the most outstanding of the varied requirements of this vast, ungraded group, new types of training have been devised adapted to the new field. With divergent aims and an extraordinary range of talent, each individual requires different treatment, new methods must be employed, original types of training must be evolved, and flexibility of procedure and program provided. Mass instruction has no place here. From start to finish it is special treatment for special needs. The author has called attention to the success which has attended technical institutes, to their work in this zone of education, and to the pioneer quality of their instruction which is being adapted to create new pathways along which young men and women in "No-Man's-Land" may rise to stations of usefulness and importance in industry and in citizenship.

A. L. Williston.[5] The author has done not only this society and the whole engineering profession to whom he makes this report, but also American industry and the cause of sound education everywhere, a service that one cannot easily over-estimate. A few of the more outstanding features of the study that are described in the report are:

1 The report calls attention to the importance of the technical institute in America in a more effective and convincing way than anything that has been previously expressed. This alone is a service of great significance and usefulness.

2 The report shows the very extraordinary success of the graduates of this type of schools. It demonstrates that for some reason, or in some way, the technical institutes included in this study have succeeded in getting results in their one- and two-year intensive courses that are comparable, in a very important particular at least, with those of the usual four-year courses of the regular engineering college.

3 The report furnishes a valuable picture of the stations in industry that these men enter, and it portrays the range and the variety of such positions as they are being opened up by the modern developments in organization and production processes that industry is using.

4 Perhaps the most striking fact of all brought out in this report demonstrates the extent of the need in industry for increased numbers of men who have had the special kind of intensive training that these technical institutes furnish. The findings are that industry is in need of 50 times the present supply of such graduates.

The author is to be congratulated particularly on the thorough way upon which he has collected his data, and upon the convincing manner in which he has assembled them to bring out the facts. At the same time, while expressing most hearty appreciation of all that has been accomplished, one cannot help a word of regret that the time and money at the author's disposal did not permit this study to include many lines of inquiry beyond those listed in the report. It would have been interesting, for example, if the study could have gone more into detail on the human side; if it could have estimated the numbers of boys and young men who today enter industry without special training, but who have latent capacities which enable them to profit by the kinds of training which technical institutes might offer. It would have been interesting if this study might have gone farther in the direction of analyzing the fields from which technical institutes draw their students and the methods by which they make the selection of those who are permitted to enter. It would also have been interesting if the intensive methods of training might have been studied more in detail so as to offer more complete explanation of many of the facts presented. It would also have been interesting, too, and of the greatest possible value, if the study might have gone far enough to suggest, in different industrial centers, the lines of new development which the technical institutes might most profitably undertake. These are only a few suggestions taken at random of the many directions in which further study in research would be of value.

President Hoover, in his inaugural address, laid emphasis upon the importance of discovering more and more ways to find leaders in every walk of life in order that one may keep pace with the new demands that science and invention are placing upon life. "One civilization after another," he stated, "has been wrecked upon the attempt to secure sufficient leadership from a single group or class." He stressed the need of drawing increasingly from the general mass and of giving full opportunity to rise, to the youth of America, through the select processes of education as far as natural capacity permits.

The technical institute is perhaps the most flexible type of educational institution at present. It lends itself naturally in large degree to carrying forward this ideal that the President has so well stated. But to accomplish this requires pioneer work far byeond anything that the author was able to find in the technical institutes described in the report. To find the answer there must be research of the first order; new ways to develop latent leadership for American industry and new pathways for "Young America" to achieve. What a magnificent challenge to the engineering profession in general, and to The American Society of Mechanical Engineers in particular!

[5] American Council on Education, Washington, D. C. Mem. A.S.M.E.

Author's Closure

The paper is in itself an abstract of greatly condensed character and presents only selected materials designed to supplement earlier partial reports. Mr. Williston's observations as to its limitations and his suggestions for further research in the distinctly human areas of the problem are wholly appropriate.

Three possible approaches to its problem were opened to the staff of the investigation. These might be called respectively the economic, the personal, and the social. The first is concerned with what industry needs in order to function efficiently; the second with what the individual needs in order to develop and use his latent powers to best advantage; and the third with the institutions which society needs in order to mediate effectively between the one and the other. With limited time, money, and human resources at his disposal an investigator must be pragmatic. He finds industry organized in large units and associations, disposed to cooperate. Existing institutions can also be enlisted as cooperating agencies, some willingly and some grudgingly, and their experience can be analyzed. But individuals are scattered, infinitely variable, and practically innumerable, making it a boundless task to survey them. The study is therefore primarily a study of industrial requirements, secondarily a study of existing institutions and their services, and only incidentally a study of individuals and their personal needs. This third aspect was not at any time out of the minds of the staff.

It may be recalled that the two full-time members had both had extended experience and wide contacts as personnel officers in industry, and the third had been for a time director of a school of industries. What Mr. Williston proposes is magnificent, but it is a task for years rather than months.

The slow and precarious growth of the technical institutes as a group has undoubtedly been due in part to the lack of solidarity among the existing institutions and their faculties. Wisely, these schools have sought to preserve a high degree of individuality and local adaptiveness and not to fall into ways of standardization. In doing so they have stood apart, emphasizing their dissimilarities and failing to make common cause. They were unable to create and enhance a recognized status of their own, being too often content to be known as non-this or non-that. Their teachers suffered from a sense of professional isolation. Their graduates had no nationally recognized credentials. No organization existed for common initiative. No appeal was made to the public imagination.

It would be unfair to close this discussion without acknowledging the invaluable service which the A.S.M.E. has done to the cause of the technical institutes through its Committee on Education and Training for the Industries, in creating a common forum for the discussion of these problems. Without the stimulus given by this committee, it is doubtful if the present study would have been undertaken.

MAN-52-8

Management of the Small Manufacturing Plant: Its Characteristics and Advantages

By CROSBY FIELD,[1] BROOKLYN, N. Y.

Having ascertained by the four standards of comparison of size of plant that small plants greatly predominate this paper suggests two reasons for this large proportion: first, that constantly changing needs are being fulfilled by new products, requiring plants in the pioneer and expansion phases of industrial life, which plants must be relatively small; and, second, the higher efficiency that small plants seem to possess.

In order to arrive at a basis of measurement by which plants may be compared, their differences in each of their activities are evaluated in an approximate fashion, and these form a composite figure which has great influence on the plant's chances of success. Although this factor has been quite generally understood, no name has yet been given to it; hence the name "degree of uniquity" is suggested, and the effect of volume and other operating influences on this factor are discussed.

In discussing the personnel of a small plant relative versatility is stressed and also the tremendous advantage enjoyed by the small plant in having the higher incentive of part ownership for the higher executives and the immediate and concrete interrelation between effort and resulting bonuses among the subordinate keymen. General organization, research, retaining of consultants, etc., are mentioned.



BEFORE proceeding to a discussion of the management of the small manufacturing plant three questions must be answered: First, what is a small plant? Second, is there a sufficient number of small plants to warrant consideration? Third, are their chances of continuing to operate sufficiently great to warrant an investigation into their characteristics of management?

What Is a Small Plant?

Naturally any question of size is purely relative, and there are many standards of comparison possible. The most frequently used are:

(A) Average number of wage earners employed
(B) The power consumed
(C) The value of production (sometimes modified so as to use instead the value added by manufacture)
(D) The capital invested.

When considered by any one of these standards, it will be found that plants group themselves by each standard in a similar fashion. These all show a larger number of establishments in certain groups than in others, although the relationships existing between groupings of plants according to the various standards may not be the same.

Again, these standards have to be considered from the viewpoint of comparison of the size of the plant, considering all manufacturing plants in the country as a whole or only those in the industry under consideration.

If any one industry be considered at various times over its life, its growth can be considered in four phases having quite distinct characteristics. These four phases are:

1 *Pioneer.* In this phase all of the four characteristics increase, and usually each shows very closely the same percentage of increase. This is the phase of the very small plant.

2 *Expansion.* During this phase (A) and (B) continue to increase, but (C) and (D) increase very much faster. This is the phase in which large and small plants are both found, and the total number of plants is relatively numerous to that to be found in the other phases.

3 *Consolidation and Stabilization.* In this period (A) may even show a decrease or, at any rate, a very slow increase; (B) usually increases quite rapidly; (C) increases slowly; and (D) tends to increase slowly or remain stationary. In this phase the number of plants decreases, but the average size increases.

4 *Disintegration.* During this period the industry is losing place to other newly arriving industries. The tendency is for all of the foregoing to show a decrease; (A) and (B) rapidly, (C) less rapidly, and (D) very slowly, sometimes remaining constant. In this period the average size of plant decreases. In rare cases the number of plants may actually increase, showing a transplanting to new locations and subsequent building up there, after the fashion of a new pioneer phase.

Obviously the main objective of management in each of the four phases may be quite different, but, as is shown farther on, certain characteristics, predicated upon size, predominate.

In this paper the index used is that of average number of wage earners, for two principal reasons:

1 The majority of the problems of management revolve about the question of labor, and it therefore predominately influences the characteristics of plant management.

2 The number of laborers is a common denominator not involving variation in price of product or in daily wage rates; it is therefore more general than the others when plants in various parts of the country or during different years are compared.

When it comes to defining a small plant in terms of number of wage earners, then authorities[2] certainly vary.

Cohn (1) mentions a small plant of 200 to 2000 men.

Dennison (2) gives the following interesting classification:

Small plants up to 500 employees

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[1] Vice-President, Brillo Manufacturing Company; President, Flakice Corp. Mem. A.S.M.E. Mr. Field holds the degrees of B.S. from New York University, M.E. from Cornell University, and M.S. from Union University. From 1912 to 1914 he was associated with the General Electric Co., and during the following year was engaged in private consulting practice in New York City. From 1915 to 1917 he held the position of chief engineer of the Standard Aniline Products, Inc., resigning to enter the Ordnance Department of the U. S. Army. Upon his return to civil life he became engineering manager of the National Aniline & Chemical Co., Inc.

Contributed by the Management Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

[2] Number in parentheses that follow the names refer to the bibliography at the end of the paper.

Plants having 500 to 1000 employees
Medium plants, 1000 to 5000 employees
Large plants, 5000 to 10,000 employees
Very large plants, 10,000 or over.

On the other hand, other authorities consider the number to be as follows:

Cordeal (3), 100 to 300 men
Alden (4), under 125
Cockshott (5), 100 to 150
Dykestra (6), under 150
Machinery, London (7), 50 to 150
Bailey (8), 150 to 400
National Industrial Conference Board (19), 250.

TABLE 1 DISTRIBUTION OF ESTABLISHMENTS EMPLOYING SIX OR MORE WAGE EARNERS, BY NUMBER OF WAGE EARNERS PER ESTABLISHMENT, 1914 TO 1923[a]

	Number of establishments			
Wage earners	1914	1919	1921	1923
6 to 20	53,954	54,317	53,771	54,609
21 to 50	22,879	25,176	23,898	25,212
51 to 100	11,070	12,370	11,047	12,346
101 to 250	8,465	10,054	8,532	10,023
251 to 500	3,108	3,596	2,916	3,835
501 to 1000	1,348	1,749	1,241	1,784
Over 1000	648	1,021	645	963

[a] It is assumed that, by omitting all establishments with less than six wage earners, the fact that the censuses of 1914 and 1919 included establishments whose products were valued at less than $5000, whereas the later censuses did not, may be disregarded.

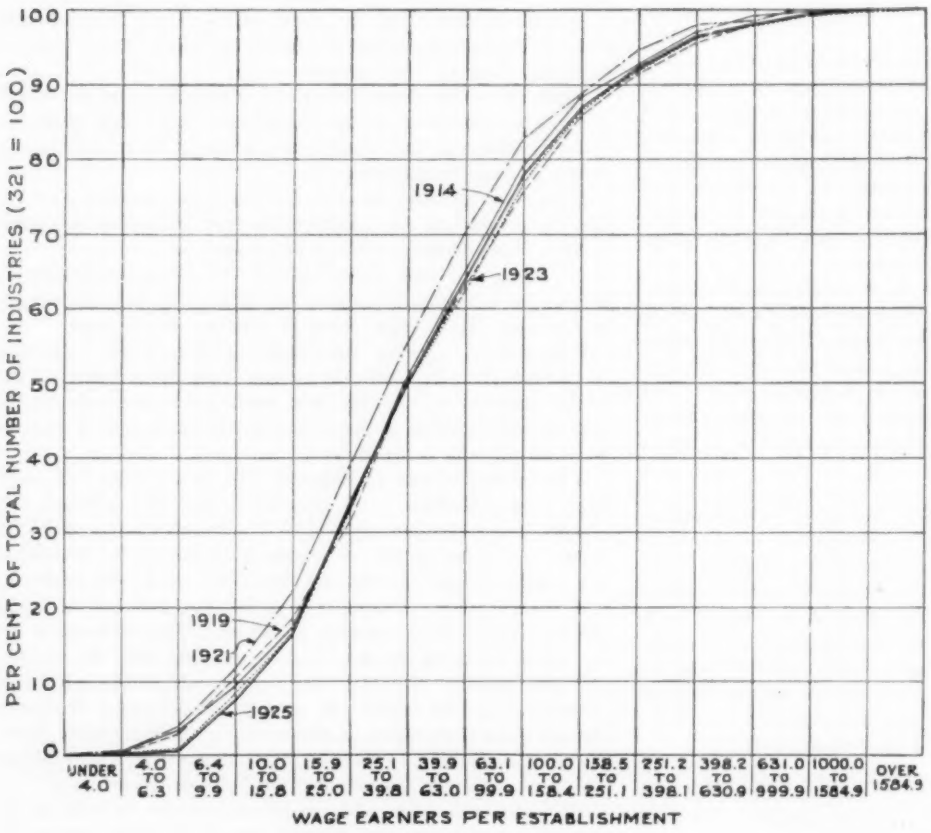


FIG. 1

In spite of these widely divergent views, Thorp, who has studied this question probably more than any one other man, in his Census Monograph (9) gives a dividing line of 250 employees, whereas in a later study (10) he gives a chart (Fig. 1) showing the frequency of plants. This illustrates the tendency for the plants to concentrate at two peaks: first, a peak at about 100 employees per plant, and next, a peak at about 20 workers, there being an actual decrease in the number of large plants. He further discusses in considerable detail a study of 321 industries making up this chart, which employed from an average of 1.2 in the cheese industry to 1086.9 in the rubber boot and shoe industry. There were seven establishments having over 500 workers each and 70 with over 100.

Thorp (11) also gives a tabulation of this. (See Table 1.)

Note that the number of plants in the United States employing over 1000 men is less than 1000. If there be added to the able those 90,000 small establishments employing less than six wage earners, the number of plants to be classified as small is surprisingly large; in fact, no matter what divisions the authorities quoted may select for their distinction between small and large, all are agreed that the small establishment shows no tendency to disappear.

We are unable to determine whether the small plant exists in such large proportion because of the fact that our numerous and always increasing number of wants are creating new industries, which being in the pioneer or expansion phases naturally are in the early stages of their growth, and therefore relatively small, or whether it is not a question of the small plant having a certain inherent superiority which permits it to compete. As Thorp so succinctly puts it in referring to two industries he has just finished studying, (12) "both of which confirm the well-established principle that at any given time and at any given stage of the industrial arts there appears to be a size of plant that is most efficient." We may perhaps amplify the statement by pointing out the influence of the stage of transportation and communication, and also the influence of density of population and marketing machinery. Thorp gives a summary of advantages possessed, respectively, by the large and the small plant (13), in which he mentions certain economies in production, in marketing, in management, and in financial administration. He also classes certain industries which are more eligible for large enterprises than others. He says:

> In general, the following types of industry appear to have developed production on a large scale to the greatest degree:
> 1 Industries which require a large capital investment, particularly in plant and equipment: Sugar refining, copper smelting, steel mills.
> 2 Industries which are monopolies, and which have a sufficiently large market to make operation on a large scale feasible. This includes artificial monopolies, such as those based on patent rights, as well as the monopolies by nature: Public utilities, manufactured ice.
> 3 Industries in which a natural resource is required and in which that natural resource is limited in amount and localized in geographical distribution: The manufacture of lead and zinc products.
> 4 Industries in which the product is capable of standardization and particularly in which a test for quality is required: Sugar, salt, meat packing, etc.

5 Industries in which the product is highly complex and can be constructed, therefore, only by an intricate fabricating system or a large and diversified organization: Typewriters, adding machines, textile machinery, and automobiles.
6 Industries in which the product is large in size, requiring complex equipment for construction and large capital investments: Shipbuilding, locomotives, ordnance.

Some of the general types of industry in which small-scale manufacturing is necessary are:

1 Industries whose product cannot be standardized and establishments which attempt to make products to suit the differing tastes of consumers. Such industries produce "tailored" suits, high-grade furniture, art goods, finely bound books, etc.
2 Industries producing for a small market, such as those manufacturing artists' materials, nets and seines, models, and patterns.
3 Industries in which the local market is small and whose product has a high transportation cost. In the manufacture of artificial-stone products, or bricks in many localities, the activity could never be conducted on a large scale because of the limitation of the market for its product and the expense of transportation.
4 Industries in which the material used is widely scattered and cannot be concentrated because of high transportation cost or rapid deterioration. Cheese factories and cider mills may be included in this class.
5 Industries in which skilled labor is the chief element, such as engraving, job printing, etc., whose products are really services rather than commodities.

The foregoing classification is believed to hold when a cross-section is made of all industry at any specific time, but is believed to leave out of consideration several factors primarily connected with growth.

It is obvious that a new industry can start only in a small way. This new industry may be merely specialization in one of the branches of a large industry and the development of that branch until it becomes a specialty by itself. The fundamentals remain the same, however, as the pioneering can be done only on a relatively small scale to be successful.

The foregoing data indicate that a plant is small when it has an upper limit of employees of from 100 to 250 workers, that this type of plant forms the greatest in percentage of total establishments (though producing barely more than half the total output), and that there is no tendency for it to disappear; on the contrary, it would seem as though it was even better than holding its own. As the questions asked in the first paragraph have been answered, the author will now proceed to the discussion of the details of management of the small plant.

Protective Influences

What are the criteria of success in management? Many have been proposed, but the two that apparently have the most widespread acceptance are a continuing increase in gross volume accompanied by a continuing increase in net profit. The ratio of the latter divided by the former need not necessarily increase, nor even remain constant, to show success; but too great a decrease indicates a change in conditions to be pending that acts as a forerunner of possible difficulties.

These criteria come as judgment after the act; what can be used before the act as a prediction of result?

It is well recognized, as Kimball states (16), that "every manufacturer must expect to rest his chances of success on one of three general factors; namely, monopoly, quality, or price." (Some authorities consider as a separate factor what they call service, the ability to deliver the material when or where wanted, or in the special shape desired.) As is usual with general factors, they must be studied carefully in their specific aspects as applied to the individual case before rating their influence. Thus monopoly, whole or partial, may be due to patents, to strategic location, to favorable sales combination, to indirect control of the purchaser by influences other than those due to the business in hand, to reciprocity, to local pride in a local industry, to transportation peculiarities, to franchise or other legislative control, and countless other factors.

Looking at these general factors from another viewpoint, and their numerous interrelations, it is quite likely that they in turn are but aspects of a still more general factor. This more general factor further predetermines the proper size of plant, of selling organization, of financial structure. The author ventures to give this factor a name, with full realization of the fate that usually falls to those who risk too broad a generalization, especially when accompanied by attempted definition of new terms, because it is believed the advantages of having such a term to apply to the daily solution of management problems warrants the effort.

Manufacturing plants and their selling organizations exist for the purpose of supplying commodities to fulfil human needs. With each human being the specific definition of that need varies slightly from that of his neighbor, but it is possible to group individuals into classes whose needs can be fulfilled within a range for the fulfilment of which it is possible to design a plant and organization. The only excuse for such a plant is that it has selected a field for operations in which it has advantages which render it unique. Unique is defined (17) as "being without a like or equal; single in kind or excellence; sole." The noun uniqueness has a general overall flavor; hence the term "degree of uniquity" is suggested as implying a relative degree of compliance with its original or logical uniqueness. A firm may be unique in the articles it produces, the process of manufacture, the way it sells, the territory in which it sells, the trade to which it sells, its fashion of shipping, the method of receiving its pay, its advertising, or even the power given it in the public mind by the personality of one of its members or employees. The degree of uniquity it enjoys is demonstrated by its degree of monopoly, or the quality or price of its products, and is accompanied by its growth in volume and profits.

It naturally follows that a plant should be as large as it can without sacrificing too many degrees of uniquity, for there is no room for two plants having the same degree of uniquity. One or the other must gradually withdraw from parts of territory or types of customer, thus changing the relative degree of uniquity.

As the plant grows, there is constant temptation to take on new lines, to expand territory, or to cut prices. Each such step is accompanied by a decrease in the degree of uniquity, with its subsequent dangers. Growth by expansion of territory is usually the least dangerous, because of the universality of similar needs among our countrymen everywhere, but every small enterprise pays dearly for its right to claim "national distribution."

The realization of the need for a large degree of uniquity in a small plant to protect it from competition is one reason so many small plants start as manufacturers of a specialty. If fortunate enough to select a specialty that is going to grow into a huge basic industry, such as steel, automobiles, etc., the growth of the plant will be great. It is, however, not unusual for a specialty of a small industry to grow to a size larger than the original industry and to completely overwhelm it, changing not only its entire aspect but the ownership of the controlling companies.

This is often accomplished by acquiring a considerable degree of uniquity in only one phase of operations, such as the discovery of a new use by a slight modification of manufacture or marketing, or by a change in manufacture due to an invention.

Every plant, large or small, should devote its attention to maintaining or even increasing its composite degree of uniquity, and in certain phases the advantage therein lies entirely with the small plant. The large company must have volume; to get volume it must sell everybody, it must sell everything (i.e., a complete line), it must sell everywhere. Each approach to universality in each phase lowers the degree of uniquity, save perhaps in actual production where the greater amount of available money may render possible the purchase of a greater degree

of uniquity due to research on product and process. It is a strange commentary that the large companies availing themselves of this method of obtaining uniquity is relatively small.

There are certain advantages which must ever remain with the large plant. Foremost is in obtaining favors that money can buy. This gives the larger plant a tremendous superiority in bargaining power, not only in the buying of its raw materials at the lowest possible prices, but also in competitive selling, which after all is a kind of buying where the flow of money is reversed. Not only in selling its products, but in selling its securities and in patent litigation, the money power of the large plant makes a formidable obstacle to the small plant against which there is only one weapon for the small plant to use—initiative almost mounting to daring, (14) in strengthening its position in so far as degrees of uniquity are concerned.

From the viewpoint of the small plant, in sizing up its opponent, the large plant, it must consider it very much from the viewpoint of the inferior army in combat. The victory does not go to the general with the largest forces nor the largest supply, but to the one who can get, to paraphrase General Forrest, "the mostest men [and the mostest supplies] thar fustest."

The small plant that endeavors to compete with its larger neighbor by making everything that the larger plant makes, puts itself in a very unfortunate position. The strength of the small plant as detailed is essentially specialization, either specializing in product or in method of manufacture, or in marketing. This specialization in marketing may comprise intensive work in a limited territory or a new and novel means in a larger territory. The specialization in the method of manufacture usually comprises the development of special machinery, preferably protected by patents, affording the small plant an opportunity to realize on its manufacturing cost difference. All these advantages merely increase its uniqueness when compared with its larger competitors.

A plant normally starts, therefore, because it is in a unique position to fulfil certain needs. This composite degree of uniquity is composed of numerous factors, each representing a degree of uniquity of one activity of this plant compared to the same activity of other plants. The precise numerical figure for the measurement of this degree of uniquity would be difficult to arrive at, but may be normally considered to be the unit dollars-and-cents advantage over other ways of fulfilling that need. As the plant grows it soon arrives at a place where due to expanding business one of the component factors of the composite degree of uniquity becomes greatly diminished. It then becomes a matter of much concern whether to still further increase the volume and thus noticeably diminish the overall degree of uniquity or whether to maintain that degree and permit the volume to remain constant. The ultimate size of plant, therefore, should be that size which can produce the greatest volume with the least marring of its degree of uniquity.

Generally speaking, there is room for only one plant having a certain degree of uniquity; consequently, the plant should aim to become the "largest of its kind" within the shortest possible time after starting. This, of course, is just another way of saying that the plant should be the largest having that degree of uniquity.

One movement that has gained considerable momentum in the past decade has been the so-called "integration of industrial operation." (20) This is an attempt to obtain the advantages of volume and of uniqueness in the same organization, maintaining the plants of a size and number tending to the greatest degree of uniquity and simultaneously providing an overall volume that warrants those advantages that accrue alone to size. The integration may not only be along the matter of plants, but also sales organization or other aspect of the business. In each case the aim will be found to be the same, and the greatest advantage accruing to the integrated industry is its bargaining power and those other advantages that money alone can buy.

Characteristics of Personnel

Specialization as a method of strengthening the small plant's uniqueness has been emphasized, but when the personnel is examined, a strange paradox presents itself. For success, the small plant requires the greatest specialization in product and method, and yet the greatest versatility in the mental attributes of the men concerned with management. A few moments' reflection will show this. A man's time may be occupied either by performing one function and applying it to a number of things (the so-called functional organization) or by performing several functions connected with some one thing. When the plant is small enough the man at the head must naturally perform all three functions in the tripod of manufacturing—to wit, production, sales, finance. As the plant grows larger, specialization, or rather functionalization, takes place, and the president hires a factory manager, a sales manager, and other functional heads, but he himself in the small plant must perform all these functions.

One of the characteristics, therefore, of the personnel of a small plant is its versatility. Each man in the plant, from president to foreman, will be found to perform a larger number of functions than a man of corresponding position in a large plant. Indirectly this versatility of mind points the reason for so many failures in small-plant management. Because a man is versatile he is inclined to get into several businesses or try to make his business go into related lines. He does this not only because of his desired increase of income, but also because of this versatility of mind.

Strange to say, this versatility of mind is not so common in an industry just beginning, and perhaps that is one of the reasons so many small plants are never able to survive the pioneer phase. The hardships of pioneering require a degree of perseverance that cannot even politely be termed anything but obstinacy. Obstinacy may not necessarily imply a low order of intelligence, but the results of its application in practice usually preclude the acquisition of that culture which makes for versatility. Culture and intelligence are not necessarily one, but are more often found together than either one by itself. Certainly the lack of income in an industry not yet past the pioneer stage does not attract men having that culture and who are usually comfortable in a better established line. That "intelligent patience" (18) which is the prerequisite for all research and other pioneer work fades rapidly when confronted with an empty stomach.

This required versatility is well brought out by Cole (21), who compares the simplicity of ship navigation in two dimensions, or even that of the air in three dimensions, with that of a manufacturing plant with its manifold problems—it is N-dimensioned. In any one of its numerous dimensions may lie the hidden rock of failure.

Alford and Hannum (15) in their startling Table V show that the small plant has the advantage in the output per man. Just why this should exist is of course a matter subject to many opinions, but the author firmly believes that one of the principal reasons is the fact that those responsible for the details of operations affecting costs are closest to the profit and loss in the industry. In other words, there is no incentive like ownership in an enterprise, and when the manager is part owner and when the superintendent and foreman share in the form of bonuses from the profit attained by their operation, then each has the greatest incentive for efficient management. It is not that there is any particular difference in the desire or willingness on the part of the men, but the cause and effect are so closely related

and the one follows the other so promptly that there can be no mistaking their relationship. In a small plant no mystery exists in the minds of the men making and selling the product of the relation between costs and profits. There are no central office charges or huge overheads to be absorbed, and in their absorbing to distort charges. Each foreman can figure concretely how many of a kind he must make with a new machine in order to pay for it or not to affect either the profits of the company or his own bonus.

In the management of the small plant the keeping of the overhead to a minimum is a prime requisite. There is nothing that chews up profits quicker than useless records, and records all have that well-known tendency to become useless unless they are constantly used. In order to be constantly used, they must be of prime interest to those most concerned. In one plant the policy has been to keep no basic records unless somebody's pay depends on it. All the production records are under the paymaster, and it is indeed rare that errors enter, for any error is going to affect somebody's pay, and naturally if this is affected in the wrong direction an immediate howl is made by the party affected. If, on the other hand, they are affected in the other direction, then the foreman and his bonus create the other situation. A summary of these records is studied by the operating committee twice a week at a meeting which is primarily for the study of these records, which have of course been boiled down by the paymaster into summary sheets. At this meeting any other business that may be pressing is brought before this committee, but pains are taken to let the committee understand that in working as a committee it is purely advisory, the responsibility for functioning remaining with the individual.

Type of Organization

This mention of the "operating committee" brings up the question of the type of organization for the small plant. Any manufacturing organization naturally divides itself along the lines of its three principal functions—sales, production, and finance. In the smallest-size plant all functions are headed up by one man, who frequently takes on as silent partner a financial backer. In the larger size of small plant the production or sales is alone handled by this one man, the other functions being handled by another, who also acquires a substantial share in the enterprise. From this split-down in each of the two operating departments, sales and production, the organization is decidedly line, the versatility of the keymen being depended upon for staff functions. In the next larger-size plant, certain staff functions may be split off, generally a superintendent to handle labor, a plant engineer to handle equipment design, construction and sometimes maintenance, and the office, including paymaster, and sometimes purchasing agent. Similarly, the sales organization is separated from credits, and territorial divisions enter.

Depending upon the nature of the business another function becomes sometimes most important, particularly in those industries which are of a contracting or jobbing nature. That is the function of designing for proposals or estimating. Whether or not the estimator be part of the sales organization or part of the factory organization depends greatly upon circumstances, but normally will be found to be under the engineer who in a small plant is both plant engineer and design engineer.

Our typical small plant now has 100 to 250 employees, and if it continues to grow it must be classed as a large plant. Our key personnel must still remain versatile, and comprises only seven men, enough still to share directly in the profits by having a share in the ownership. These men are the chief executive, sales manager, credit manager, production or factory manager, superintendent, engineer, and purchasing agent. Further profit sharing among territorial sales managers and foremen is easily obtainable by means of commissions and bonuses, the close contact of the heads with affairs and men rendering such procedure profitable. This gives the greatest incentive to effort, and, as has been stated, is probably one of the reasons for the greater efficiency of the small plant.

For committees, which should be purely advisory, only two in the factory, safety and operating, and one comprising sales and credit are desirable. At these conferences hidden difficulties are frequently brought out and settled.

Research and Development

Since the small plant must keep down overhead, it suffers from lack of staff, and it therefore would seem that the small plant is the ideal client for the professional consultant. Obviously the small plant cannot compete with the staffs and laboratories of the large concern, having a staff of a caliber and size to take care of all their needs; nevertheless, the retaining of professional consulting services and realizing upon them forms one of the most difficult problems of the small-plant manager. The small plant must specialize, and by conquering its specialty it very soon gets out of the depth of the professional consultant who may then become even something of a liability. On the other hand, the small plant cannot be expected to keep in touch with the advance of the art as a whole; hence a compromise must be effected whereby the small-plant manager is brought down to date by the consulting expert on all matters connected with the art as a whole, retaining for his own small staff the specialization work that pertains to his own manufacture.

This requires, of course, versatility on the part of the plant manager, and it may further be displayed not only in the hiring of engineering and manufacturing consulting services, but further in the retention of other types of professional consultants, such as patent attorneys, auditors, and the like. The man at the head of the small plant must be versatile enough to make proper judgments when presented with the technical facts and advice of the various consultants he should retain.

One place that the small plant very frequently falls down is in the development of its own machinery and equipment. It is too easy to buy standard equipment and operate it. In so doing the plant is not putting itself in any way in a position to compete with its rival, who is of course going to receive the benefits of the same machine. There is no resulting favorable differential in uniqueness obtained. The modification of a standard machine to produce a specialized product is one of the surest ways that the small plant can achieve success.

Ranck (22) in an able article tells how his concern obtained great advantages in a specialized product by developing machines twice as large and able to handle material twice as wide as could be provided them by the standard machinery manufacturers. This resulted in a small plant having the largest machines and enabled it to undertake work that the large plants with their small machines could not do. Mr. Ranck, as might be expected from such a course, evolved the following three suggestions for a small plant:

1 Make the best product
2 Watch costs; fight them with daring
3 Watch shifting markets, particularly with respect to the salability of the product.

Distribution Effects

Depending as it does upon volume, the large plant naturally tends to manufacture more of its own raw materials, which means more products to use or sell, which means an ever-increasing line of products, marketed more and more upon a price basis and with constantly increasing fixed capital investment.

All this tends toward a rigidity of operation, a building up of inflexible policies and other attributes that render it comparatively immobile, while the small plant can succeed better because it can move quicker. In order to maintain its mobility it must be in close contact with its customers.

Generally speaking, the more successful small concerns are found closest to the ultimate consumer, working back into production of its raw materials only as they increase in size, and the larger concerns are found nearest the crudest materials, such as mines or other original sources of raw material. This is good policy in that it permits the more ready establishment by the small plant of that uniqueness referred to. The contrary policy, of manufacturing for a large plant, thus becoming a so-called "satellite plant," is frequently profitable, but exceedingly hazardous.

Distribution costs form an increasingly important share of the total. In selecting the right customers and the proper market the small concern has several advantages; the large concern seeking to dominate the line must sell everybody, and in selling everybody takes many accounts at a loss, whereas the small concern with limited output can be more selective in its accounts.

Cole (23) refers to the most usual "entangling alliances" to be avoided as dependence upon a single or uncertain source of supply of raw materials, a single product, or a single customer or outlet. Yet if the composite degree of uniquity be great enough, a single product is often the very best guaranty of continued success. In order to accomplish this, however, it must be protected by a trademark and a distribution that make it difficult for a competing brand to get into the ultimate consumers' good graces.

Summary

There are four standards by which plants are compared according to size, which are: wage earners, power consumed, production value, capital invested. By any such standards of comparison the small-size plant is found to be predominantly in the majority of the number of establishments, and detailed investigation along the lines of that of comparison by means of wage earners has been given. There are four phases of the life of industry, called pioneer, expansion, consolidation, and disintegration, and the general characteristics of relative number and size of plants in each of the four phases have been discussed. It is probable that the preponderance of small plants is due to two factors; first, the large number of industries in this country which are at present in the pioneer or expansion phase, during which two phases the size is relatively small; the second factor is demonstrated to be a certain type of superiority in efficiency that plants of a certain size have been found to attain. Whether this certain size can be called small or large depends upon a variety of factors, but it is certain that the most efficient plant is neither the very smallest nor the very largest of its kind. The conditions under which the small plant or the large plant may attain this most efficient size have been discussed, and it is believed that the small plant—i.e., the plant having less than 250 employees—will be found in most cases to be the most efficient.

In studying the relative advantages of the small and the large plants, in addition to the usual factors of monopoly, quality, and price given, it is believed that a more general factor termed the degree of uniquity which takes into consideration these three and in addition numerous other factors, all external to the organization and size of the plant itself, and which may be either favorable or unfavorable, should be introduced and used. The most efficient size of plant would seem to be that size determined by a compromise between the degree of uniquity and the volume of production. This balance may be slightly changed from one side to the other by matters of personal efficiency of the guiding minds of the organization. Several of the factors affecting this relationship have been discussed.

Among the characteristics of personnel discussed, that of relative versatility between positions in the small and large plants has been mentioned, and the greater versatility required by all the personnel of a small plant is seen to be both limited in supply and at the same time to be responsible for much of its efficiency.

One of the strongest advantages enjoyed by the small plant is believed to be the close relationship between incentive and effort produced by the element of share in ownership that is much more likely in a small than a large plant. In addition, is the fact that cost and profit, one person's effort and its result, are immediately seen instead of the long-time lag that comes in large organizations, not to mention the chances of losing that relationship in the whole averaging of a large number of factors, sure to occur in the large plant.

Some remarks regarding the organization of the small plant have indicated a line organization with very few staff positions. Committees, when used, should be purely advisory; the carrying out of the suggestions remain the responsibility of the executives in the line and according to their line responsibility. Some remarks on internal research and development and the retaining of consultants indicate the difficulties of the small plant. Inasmuch, however, as this is one of the surest ways of maintaining its degree of uniquity, it must be one of the most carefully studied. Remarks on the effects of distribution and methods of combating have indicated that not only must the small plant be studied internally, but also from the aspect of its distribution and keeping in mind that increasing distribution is one of the principal factors tending to reduce the degree of uniquity.

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(28) Whitehead, A., "Establishing a Small Engineering Works," 1922, *Eng. & Indust. Manag.*, v. 7, pp. 502–6, 540–2, 571–3; v. 8, pp. 3–5, 39–41, 75–7, 121–3. Gives advice in the selection and appointment of a staff for a small factory; the organization plan, functions of each department, and the division of labor within the departments; what the managers might reasonably expect from the production department.
(29) Brown, G. C., "Profitable Methods for the Small Factory," 1924, *Manag. & Admin.*, v. 7, pp. 161–7, 305–10, 431–6, 567–72, 683–8. Discusses the special fields open to the small factory; the distinction between the large and the small factory; the inadequacy of management in small plants; outlines some profitable methods for a small organization in which standardization is guaranteed; wage incentives and profit-sharing; distribution of overhead to jobs.
(30) Ross, H. W., "Management Difficulties in Small Factories and Their Solution," 1924, *Indust. Manag.* (London), v. 11, pp. 207–8, 377–9, 467–8, 470. Gives some common examples of difficulties in the purchase of materials and in the acquisition of a credit rating.
(31) Carpenter, C. U., "Making a Success of the Small Manufacturing Business," 1925, *Manag. & Admin.*, v. 10, pp. 125–8, 195–8, 287–9. A general study of the application of management to a small business in its early stages; management in the shop, and in selling its product.
(32) See reference 21.
(33) Lynch, F. J., "Even-Flow Production; What It Can Mean to the Small Plant," 1925, *Factory*, v. 35, pp. 909–10, 950. The president of the Sun Tube Corporation, Hillside, N. J., tells a cheerful story of the opening and running of a small factory. The one described manufactures collapsible tubes for shaving cream, tooth paste, etc.
(34) Wherry, H. P., "Management Problems in the Small Plant," 1926, *Mfg. Indust.*, v. 12, pp. 207–10, 257–60, 355–8, 419–22. Shows the similarity in the problems of the large and small plant; the advantages of the large plant; the place of research in the small plant; the small company's handicap in advertising.
(35) Cole, D. S., "Solving the Problems of Composition in the Small Factory," 1927, *Indust. Manag.*, v. 73, pp. 80–90, 155–60, 229–34. Discusses the possibilities of stimulating business by an analysis of products; the possible elimination of waste by the application of research; grouping of small plants of allied industries; the small plant's handicap when it comes to quantity production.
(36) Dwyer, P., "What Is Wrong With the Small Foundry?" 1927, *Indust. Manag.*, v. 74, pp. 33–9. Points out that although the small foundry occupies a well-defined and necessary place in industry, it is in a highly competitive field, where exact and scientific methods are used and where guesswork has no place.
(37) Simonds, H. R., "Improving Small Plants Economically," 1927, *Iron Tr. Rev.*, v. 81, pp. 1–3. Tells about the reorganization of the Coates Clipper Manufacturing Company, Worcester, Mass., according to modern manufacturing principles, the gradual replacement of old equipment, and the development of an efficient and profitable small business.
(38) Wherry, H. P., "New Methods Increase Production 100%," 1927, *Mfg. Indust.*, v. 13, pp. 41–4. Describes some cost cutting which has meant substantial savings for one small plant.
(39) Wherry, H. P., "Results From Reorganized Financial and Sales Methods in a Small Plant," 1927, *Mfg. Indust.*, v. 13, pp. 115–19. Tells briefly how accounting and production control have simplified the work of the plant of Rossendale-Reddaway Belting & Hose Company.
(40) Alexander, A., "What of the Small Factory?" 1928, *Nation's Business*, v. 16, pp. 64, 67–8. Gives a short statistical summary showing that the small manufacturer has the same chance he has always had. "The race is keener today, there are more people in it, but the prizes are greater."
(41) Hoyt, C. W., "What Chance Has the Small Manufacturer?" 1928, *Nation's Business*, v. 16, p. 56. Direct competition is said to be possible, provided the small manufacturer selects one product, redesigns it, and subjects it to unique and intensive marketing.
(42) Pavey, W. B., and others, "Making a Profit in the Small Plant," 1928, *Mfg. Indust.*, v. 15, pp. 187–90. Points out that the principle of industrial management, when applied to the small plant, is just the same as when it is applied to the large; the difference is in the application. Gives several advantages possessed by the small plant, as seen by officers in such organizations; the chief disadvantage is said to be the multitude of duties placed on executives. Research is considered imperative for the small factory.
(43) Roberts, G. E., "Small Concerns Still Possess Advantages," 1928, *Comm. and Finance*, v. 17, p. 920.
(44) Swanson, A. E., "Advantages of Knowing Costs," 1928, *Mech. Wld.*, v. 84, pp. 81–2. Shows how a small plant may develop rapidly into a large one without having sufficient records of costs in its development stages. Recommends that every manager familiarize himself with the details of costs in all stages of business.
(45) Dykstra, J. E., "Management of Small Industrial Plants," 1929, *Cassier's Indust. Manag.*, v. 16, pp. 51–3. Discusses the determination of a plant's production capacity in order to practice control in accordance. Some system of time study is considered indispensable to the small factory manager; other important factors are grouping of equipment, use of new tools, and intelligent buying.
(46) Norton, C. F., "Why We Prefer to Stay Small," Howell Electric Motors Company, 1929, *Printer's Ink*, v. 147, pp. 133–4.
(47) Hopper, S. J., "Plant Growth Affects Management," 1930, *Iron Age*, v. 125, pp. 75–6. Outlines in a general way the problems brought about by the expansion of a small factory, especially in the selection of the minor assistants and in lowering the production cost of the product, in order to justify the factory expansion.
(48) Burnham, "Building Your Own Business," 1923. This non-technical treatise is one of the most concisely stated and brilliantly arranged polemics in favor of the small company. It gives forty-six cases illustrative of the various points made, and is a book that should be in the library of every engineer.
(49) Reference to dictionaries demonstrates that the term "uniquity," although at present classified as rare, not obsolete, is etymologically correct, whereas "uniqueness" is not. "Unique" is Latin and should take the Latin suffix "ity," not the Anglo-Saxon "ness;" thus, ubiquity.

Discussion

D. B. CHARTERS.[3] It is the writer's belief that some of the good points claimed for the small plants have been slightly exaggerated, and he would like to indicate some things which might point to other conclusions being the more correct.

(1) The versatility of those in charge of the plant may well be a strong factor in the success of the concern, but the control by one or two persons has this disadvantage in that their errors in judgment may have an immediate and disastrous effect upon the small plant. Could these executives be always correct in their judgment the quicker action secured by their close contact with their plant is of course highly desirable, but in the larger plant projects must pass through several persons, generally experienced; so that while there may be some delay as compared to the smaller plant, when the project is finally complete, it is much more likely to be workable in all respects. The writer has had some experience along these lines and recalls very clearly instances substantiating the statement.

(2) Many small plants attain their "uniquity" as to price by frankly copying the output of the larger concern. All elements of expense distribution, as regards design and development, are thus avoided by the small-plant manager, and while the price of his product may be lower and the product itself just as good, it seems hardly fair to credit this entirely to the acumen of the small-plant manager.

(3) Efficiency is a broad term, but if it were based in a general way upon length of life, service rendered to the public, the ability to pay reasonable dividends year after year, surviving good times and bad, steady employment, care of the old employee, then the large plant surely is just as "efficient" as the small plant.

(4) It seems that the author has stated the case perfectly for the really successful small plant when he says, "A single product is often the best guarantee of continued success. In order to accomplish this, however, it must be protected by a trademark and a distribution that make it difficult for a competing brand to get into the ultimate consumer's good graces."

It should be noted that, in this case, efficiency has little to do

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with the matter, since the monopoly amounts in effect to a subsidy and may enable a small plant to be successful in its own field when it would last but a short time in open competition.

G. F. Gray.[4] The writer wishes to express his appreciation to Mr. Field for his very able presentation of this subject. The writer has recently had occasion to take up the management of a small firm after a number of years in executive work with large ones. Naturally he tried to start the new job by reviewing the experience and conclusions of others as recorded in the technical press. It was quite a shock to find that there was almost nothing in print on the subject. Mr. Field points out that small firms produced half the country's products and constitute 98 per cent of the manufacturing establishments. It is also obvious that their need for business and technical guidance must be greater than that of the large firms. Yet even in the transactions of our own Management Division the percentage of space devoted to their problems bears no reasonable relation to their importance. It seems that Mr. Field's paper is a distinct challenge to us to correct this condition in our own work and to urge others to do likewise. It is generally admitted that the importance of agriculture to the country justifies the unusual efforts which the Government is making in behalf of our farmers. The contribution to general welfare which the small manufacturers make seems no less important, and The American Society of Mechanical Engineers might very well become their spokesman.

The references cited by Mr. Field constitute the best bibliography on this subject that the writer has seen. It might very well furnish the beginning of a complete bibliography to be published by the Management Division.

H. O. Stewart.[5] One of the most perplexing and difficult problems of the manufacturing plant is the efficient control of the non-productive employees. This increases in approximately direct proportion to the number of non-productive operators.

Much has been done in increasing the efficiency of the productive operator. On the other hand, the efficiency of the non-productive operator is scarcely considered at all in the average plant.

Truckers, machine fixers, cleaners, inspectors, repair men, clerks, assistants, etc. set their own pace in most manufacturing plants, notwithstanding the attempts of the supervision to concontrol them, and no matter at how slow a speed they are working it is difficult to give them additional tasks and have them properly handled.

The solution of this problem depends chiefly upon a higher grade of supervision and a reward to the worker based directly upon the results of his efforts. It is, however, almost impossible to measure the results of the efforts of many non-productive operators with sufficient accuracy to set standards of wage payment.

As a result, many compromise methods have been tried. One of the rather common methods used is to pay the non-productive operators in a certain department a bonus which is proportional to the average bonus earned by all the productive operators of that same department.

The weakness of this system is that the reward is not proportional to the individual effort, but is based on the results attained by others. This system is based on the theory that the non-productive operators help the productive operators earn their bonus and that the non-productive operator should be rewarded in proportion to the increase in production over a set amount.

If one non-productive operator out of a group of ten does practically nothing for a week, his bonus would be affected but little, if any. In order to earn the same bonus, the productive operators might have to work somewhat harder or the same result would be attained if the nine non-productive operators speeded up somewhat.

The mental attitude of the non-productive operator is similar to that of great numbers of voters who feel that their votes would have no effect on the outcome of an election consequently, they will make no real effort to register their votes.

The writer believes that the lack of methods of efficiently controlling and properly rewarding the non-productive operator is the chief reason for the great number of small manufacturing plants, and hopes that systems will be devised whereby non-productive operators are rewarded in proportion to the individual results which they attain.

Alonzo Flack.[6] The author's excellent analysis of the problems of management in the small manufacturing plant may well be considered by those interested in the management of large or small manufacturing plants. There is no real reason why some small plants cannot have many of the advantages of the large plant. There are a number of small plants in operation that are perfectly designed for the rapid and economical manufacture of their products.

Labor is a predominate factor in management and takes a great deal of management's attention. Today, however, management is greatly concerned with product, equipment, processes, and methods.

The small plant has the problem of diversification. In some ways to diversify means protection. However, in most small plants many items are continued because the management does not take the trouble to find out that 90 per cent of the sales are made from 10 per cent of the items.

Monopoly, quality, or price are mentioned as the main factors of success. Service is mentioned as a possible factor. Service is a vital factor to the success of most every business.

The operating efficiency of a small plant can be improved just the same as in a large plant if correct fundamental principles are applied.

Author's Closure

The kind reception afforded the paper, and the carefully prepared discussions, whether advocating the author's thesis or opposed to it, have been very much appreciated. Most of the criticism has appended specific examples in which factors other than the fundamental factors mentioned in the paper govern, as will always be the case with individual experiences. It will be necessary, before arriving at a conclusion, however, to study sufficient representative cases to be able to state the most usual trends. Theoretically there is no reason why the very smallest plant cannot be as efficient as the very largest plant, or vice versa, but what we are interested in is not theory but the facts of the case as we may study them.

The favorable reception afforded the introduction of the term "uniquity" to cover all those other factors described, is gratifying, and it is believed that the time is not far off when a numerical scale of uniquity can be adopted and recognized as a yardstick for judging the possibilities in a particular project or existing company.

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MAN-52-9

Measuring Office-Machine Output as a Basis for Wage Incentives

By JOHN MITCHELL,[1] LYNN, MASS.

The author describes the procedure to employ in installing sound standards for office-machine work. After elimination of the unnecessary operations which a study of process sheets reveals, the various jobs are analyzed and the units in which their elements are to be measured are determined. He then takes up the determination of the value of the unit, the basis of payment and method of its calculation, the maintenance of standards set up, etc. An extensive appendix gives time allowances, rates, methods of bonus determination, and other data derived from various sources and covering a wide range of office-machine operations—addressing, typing, tabulating, duplicating, calculating, bookkeeping, etc.

THE general premise that an individual will produce more on an incentive basis than on a straight salary has led to the establishment of plans on an "as is" basis; that is, a betterment of present conditions. To pay the rank and file on such a basis without any study as to the necessity for the work is likely to lead to useless expenditure of money. It is with the knowledge that such conditions exist that the following specific approach is outlined. It can and should be applied to all clerical work, whether it be considered supervisory or routine, mental or manual, or office-machine operation.

This paper is particularly addressed to those at the top who are so busy promoting the enterprise and opening up new avenues for securing profits that they give very little thought to clerical routine, until the expense becomes so heavy that they are absolutely compelled to give it attention.

Clerical work is no longer incidental; it is an important cog in modern industry. Data prepared by the clerical organization become the foundation upon which many executives base important policies. When the typewriter was first placed on the market the consensus of opinion was that it was interesting but superfluous. Many able executives today wave aside with the same words proposals for the installation of sound standards in clerical work. Sound standards are essential for control as well as for forming the basis of wage incentives.

The first step in preparing sound standards is to determine what is to be measured. Output of office machines would naturally suggest itself in view of the title of the present paper. That is only partly true, however, because the actual operating of the machine is usually but a small part of the complete cycle of work performed by the machine operator. There is so much duplication and unnecessary work done in an office that it would not be fair to set a standard without taking into consideration the whole situation. It is therefore necessary to consider the flow of work for the entire department and organization.

Process Chart Eliminates Unnecessary Study

The process chart, a simple but efficient tool of management, was devised by Frank B. and Lillian M. Gilbreth.[2] A simple process chart showing the travel of each type of order or document from the time it is received or started until it reaches its final destination should be prepared. These charts should not only reflect the flow of work through a department, but also through the organization. They should cover every method and record in the office.

A careful analysis of these charts will disclose unnecessary and duplicate documents and operations. It may mean rearrangement of departmental set-ups to eliminate duplication of documents and operations, but this should be done wherever possible. The changes will save a great deal of study and will eliminate conditions which if allowed to exist might form a weak foundation for a wage-incentive plan.

After the unnecessary work has been eliminated, it is essential to review the work performed by each individual or "job." The best procedure for obtaining such data is through a job analysis.

Job Analyses Will Determine the Component Elements of Jobs

Harry A. Hopf, of H. A. Hopf & Co., in his paper "Improving Management Through Job Analysis," presented at the A.M.A. winter convention in 1927, defined job analysis as "that process which results in establishing the component elements of a job and ascertaining the human qualifications necessary for its successful performance." There is considerable literature available on the subject, and therefore it is not essential to dwell upon the details here. However, "establishing the component elements of a job" is the result that should be obtained to assist in the determination of what is to be measured.

What Is to Be Measured

It is extremely important to know these "elements," if they have not already been reduced to writing. Do not depend upon your knowledge or that of the supervisor of the particular job. Too often there is a wide difference between what is "supposed" to be done and what is actually done.

A careful study of the job "elements" disclosed by job analysis will point out many that can be eliminated, combined, or performed in a simpler manner. The following example will illustrate the importance of this statement.

In a typing bureau the typists inserted and withdrew the carbon paper in connection with their work, and a wage-incentive plan had been established on the basis of the number of lines typed. The typists found that the average number of sheets of typed material for each set-up was so great that the insertion and withdrawal of carbon paper represented about 20 per cent of their time. They persuaded the messenger or clerk to insert and withdraw the carbon. Their earnings were thus automatically increased by utilizing the released time for productive work.

A supervisor would have real difficulty in determining what portion of the original set-up was represented by the handling of carbon paper. A job analysis, however, would have disclosed the condition, and it would have been considered and recorded in preparing the basis for evaluating the "line." If it was not separated until after the incentive had been in operation for some time, the record would still show the valuation placed upon

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[1] General Electric Co.

[2] Trans. A.S.M.E., vol. 43 (1921), p. 1029.

Presented at the National Management Congress, Chicago, Ill., March 5 to 7, 1930.

it. This would enable the separation to be made at any time on a fair basis.

Up to this point the author has dealt with the tearing apart of existing conditions, eliminating obvious wasted effort, and with what is to be done. The next step is to determine the unit of work that is to be measured. (Examples of specific cases are given later in the form of an appendix.)

Determination of Unit to Be Measured

With the component elements recorded, it is then possible to review them carefully to see what combinations, if any, should be made. This study should be made having regard to the size of the organization, department, or group in which the work is to be performed, and to the difficulties that will be encountered in making changes.

Measurement is the beginning of all science, but no scientist ever said that everything could be weighed, counted, or measured by a yardstick. There are different methods of measuring. It is not always possible to select, at once, a unit that will be thoroughly satisfactory. There are many things that cannot be measured, but, on the other hand, there are many that can. The greatest difficulty is to convince executives that there is some way of measuring some part of the work.

The majority of executives allow the affairs of their respective organizations to be dominated by the considerations which controlled their points of view in the specialized lines to which they devoted their energies while in subordinate positions. This condition is even more aggravated in the case of clerical work. A good salesman will be promoted to be sales manager and will be in charge of the clerical work pertaining to sales. A designing engineer will become a managing engineer and have charge of clerks in that department. It goes on in all lines even down to the general foreman in a manufacturing department who will be in charge of the clerial work affecting his department; he is primarily interested in producing product, so clerical work is incidental with him.

Modern office machinery, like manufacturing machinery, should not be permitted to remain idle if it is possible to keep it in profitable operation. This should be uppermost in the minds of those who are determining the unit to be measured. For example, a job analysis of the clerical work in an order department might disclose the fact that customers' orders are read and the contents modified to factory or warehouse requirements by the reader; orders are then typed in hectograph in accordance with the modified copy; copies of the orders are made on duplicating machines; the sales or some other value is figured by calculating-machine operators; records for statistical purposes are compiled by hand and later summarized in report form by typists; and correspondence with customers and internal departments dictated to stenographers. The work will likely be given to those who are in a position to do it. A stenographer may type reports, use the calculating machine, and be an able clerk.

The department may be under an efficient manager who is producing results. He is anxious to reward his staff and encourage them to produce more. A wage incentive is proposed. It is difficult to measure the work of the individual, so it is decided to take the group as a whole and use the order as a unit. The plan is started. The clerks produce more and earn more. The manager receives praise from his chief executive. Everybody is happy.

What is done about the typewriters and calculating machines that are idle a goodly portion of the time? Why do statistical work by hand that can be performed more economically by machine? Why dictate to a stenographer when dictating machines are available? Of course, the stenographer is carefully labeled in the job analysis as "doing other work; dictation is only a small part of her job." The latter is a stock argument against the use of central transcribing bureaus.

Suppose that the job analyst had a broad experience and is not tied by politics and petty jealousies his report would read somewhat as follows:

Typewriting:

Order Department	.....hours
Sales Department	.....hours
.....	.....
.....	.....
.....	.....
	.....
Total Typing	.....
	.....

Note: It is possible to use continuous forms on certain orders and sales work. A typewriter adapted to these forms can be used, thus eliminating insertion of carbon and the tie-up of investment in more than one machine. Reports that are difficult to prepare can be handled by a specialist and produced in a fraction of the time taken by a stenographer. Recommend that all of the above typing be placed in a central bureau.

Duplicating Machines:

Order Department	.....hours	.....machines
Sales Department	.....hours	.....machines
Accounting Department	.....hours	.....machines
.....	.....	.....
.....	.....	.....
Total Duplicating	.....	

Note: The cost of duplicator rolls represents a comparatively large item of expense in this work. Proper use and care of rolls can be obtained only through careful supervision. It is therefore recommended that the above work be centralized and the investment in machines and expense in rolls materially reduced.

Calculating:

Order Department	.....hours	.....machines
Sales Department	.....hours	.....
Accounting Department	.....hours	.....
.....	.....	.....
.....	.....	.....
	.....	.....
Total Calculating	.....	

Note: It is recommended that all of the above work be performed in a calculating bureau. This will permit the employment of experienced operators and reduce the investment in machines.

Statistical Machines:

Statistical work performed by hand in the following departments, if centralized, will permit the purchase and profitable use of..... statistical equipment. (The order department is included.)

Dictating Machines:

An analysis of the dictation by the correspondents in the order department discloses the fact that a large portion can be carried on by means of form letters. The remainder of the dictation and the fill-in data required on the form letters can be given to dictating machines at a much greater speed than to stenographers.

To produce the best results, it is recommended that the transcribing be done in a central bureau.

As the operations of the calculating, statistical, duplicating, typing, and transcribing bureaus are closely related, they should be physically located together so that there will be no unnecessary travel. An adequate messenger service will be maintained between departments. A definite schedule on all work will be maintained, thus providing means of knowing when work will be done.

These bureaus, the messenger service, and machine maintenance will be under the supervision of the office manager.

What is left in the Order Department? The order readers and a greatly reduced staff of correspondents. The order is still the unit of measurement, but there is a great difference in the value given to it. It can be more easily evaluated. The

miscellaneous clerical, typing, and stenographic work which would cause difficulty in the original set-up have been removed and put in a place where they in turn can be easily measured.

What will the Order Department manager and other department managers do? Will they say to the chief executive, "We recognize the advantage of efficient use of modern office machinery; we believe that the centralization of such machinery will keep it in productive use more continuously than if it were scattered throughout our departments, and will reduce the investment and maintenance expense; it will also be possible to use experienced operators who will be continuously employed on one type of machine, thereby making it possible to measure their output either on an individual or group basis?" No. Each one will have at least a hundred reasons why it cannot be done to every one he will give for doing it. Then, as chief executive, what are you doing to do? If you were a specialist before rising to your present position, you will immediately go over the story as it relates to that department. You will confirm the present department head's objections. Then, expressing a desire to be impartial, you go to the end of the report and there you see the words "Office Manager," and you say: "Ah, who is this? What does he know about our business?" Then you call for the job analyst.

If, as already stated, the job analyst is a broad-gaged individual, he will have his handbook of standard questions and answers with him. You ask him, "What does an office manager know about our business?" He turns to Question 21 and finds the answer: "An office manager should know the best equipment for performing any particular type of clerical work; he should be able to secure the greatest output in quality and quantity from such equipment; and be able to translate requests for data pertaining to the particular business in which he is engaged into machine-hours; and produce the results requested. In other words, he does what he is told to do in the best, quickest, and most economical manner."

You then ask, "How and where can we get such a man." He turns to Question 22: "Ask W. H. Leffingwell; he will tell you all about the procurement and training of an office manager." The job analyst sticks to his story, and the result of his work will be a success or a failure depending upon whether you will face the facts and use them or judge in accordance with past experience supplemented by the prejudiced, personal opinions of your department heads. Fortunate is the organization whose executives and supervisors are willing to make impartial decisions based upon facts.

Where there is a large volume of the same type of work performed by a large staff of machine operators, such as public-utility billing, where the unit would be the "bill," it is comparatively easy to determine the unit. Where there is a variety of operations performed in a department by a number of clerks who are not confined to any one particular operation, the principal document should be considered the unit, and all subsidiary papers tied up to it. For example, the order would be satisfactory in an order department. It would be necessary to determine all the work pertaining to the order in the particular department and make allowance for orders requiring special treatment. It might be necessary to divide the orders into several classes and give a value to each class. In a shipping department, the memorandum of shipment or bill to the customer would be the unit. Again it might be necessary to divide shipments into classes such as freight, express, and parcel post. Each of these classes requires varying additional documents, and would therefore have a separate value. The work of an individual or group of individuals may be tied up to any of these units.

In centralized departments where office machinery predominates, it is usually customary to use the unit produced. For example:

Addressing Machines—Number of stencils or plates of certain number of lines, number of impressions produced
Tabulating Equipment—Number of cards and holes per card
Typewriting—Number of lines, square inches, letters, reports, or cyclometer points are used
Duplicating Machines—Number of copies produced. Where the setting up of the machine is a large factor and the copies are made automatically, the set-up is the principal unit while the running time is incidental.
Calculating Machines—Number of documents. Each type of recurring document will have on an average the same number of calculations. Therefore it should be possible to place a value on each class of document
Bookkeeping Machines—Number of entries or documents posted.

For definite data and experience of others in determining units, reference should be made to Appendix No. 1

How the Value of the Unit Should Be Determined

In setting a value or making a standard upon which to base a wage incentive plan, it is well to consider the subject under two factors, quantity and quality.

Quantity. To determine the quantity, the unit should be counted, and the time consumed in handling it should also be calculated. The count should extend over a period long enough to bring in the principal variations in volume. The overall time consumed in handling these units during the period should be recorded. This is for a general guide only.

A time study should be made. The minuteness of the study should be determined by the volume of units and number of persons involved. In all cases, the elements involved in a unit should be time-studied separately. The time for each unit should be fair. It should take into consideration unavoidable delays, personal time out, and uncontrollable conditions. It should represent what is to be expected from a good grade of clerk.

In cases where several clerks are performing the same operation, it would be profitable to make a micromotion analysis of the work. This will enable the analyst to eliminate waste motion before setting the time factor.

Quality. Too often wage incentives are given on output without considering quality. Quality must be determined and carefully set forth in writing before starting any plan. It may mean the performance of work within a definite schedule, the reduction of errors, or some factor which will prevent carelessness or unnecessary expense in the group or some other group. For example, in the case of a purchasing department, quality factors may be listed as follows:

(1) Reduction in ratio of transportation cost to cost of incoming material.

(2) Meeting "wanted" dates set by the factory.

(3) Reduction in telephone, telegraph, and correspondence expense.

It will be noted that to meet factor (1) there will be an inclination to extend the "wanted" dates so that all deliveries can be made by freight. To meet factors (1) and (2) there will be an inclination to increase factor (3) by telephoning, etc. By carefully weighing each of these and other factors in determining the value of the unit, which in this case is the purchase order, it is possible to set a fair standard.

Each standard must fit the particular conditions under which it is to operate. The total situation must always be kept in mind so that one group will not earn a bonus at the expense of another group. A clear definition of the standard should be written so that any modifications can be made and the values fairly adjusted.

What the Basis of Payment Should Be

There are several bases for payment which should be carefully considered before deciding upon a plan.

Individual. Payment on the output of the individual is very common in the case of office-machine operators. In large organizations where there are groups of specialists, it may be advantageous. The appeal to the individual may cause him or her to produce more. The clerical expense in keeping records of output and payment is greater than under any other basis.

Group. Determining the standard on the basis of the group is becoming popular. It requires less clerical expense than the individual plan. Care should be taken to see that there is a community interest in the group, otherwise it will be hard for the members to see their part in reaching the objective.

This base is best adapted to conditions where the exact measurement for each unit is difficult to obtain or exorbitant to maintain.

Supervisor. The payment of a percentage of the salary of the immediate supervisor of a group for each per cent that he reduces the expense below a predetermined amount under a predetermined schedule of conditions or service.

For example, assume that a supervisor receiving $60 a week controls a unit incurring $1200 a week expense. If we give 1 per cent for every 1 per cent he reduces his expenses while maintaining a definite schedule of service, the result of a 10 per cent reduction in expenses would be: Salary, $60 + 10 per cent = $66. Expenses, $1200; reduction of 10 per cent = $120. Therefore by paying $6, we would obtain a net saving of $114.

Such a plan should be reviewed annually and the standards adjusted to current conditions. To those who do not wish to spend the money or time to make the complete study recommended, this plan may help as a preliminary. Later when apparently rock bottom has been reached, the study should be made and a sound incentive plan established for the group.

Method of Calculating Payment

There are a number of thoroughly tested plans, such as the Bedaux, Gantt, Rowan, Emerson, etc., which can be used. These are all described in the "Management Handbook" and in other publications. The choice should depend upon which one, in the opinion of the individual doing the work, will produce the best results.

Who Should Set the Standards

Too often the task of setting standards is placed in the hands of a junior in the time-study department, if one exists, or if not, in those of a bright young clerk, who has neither the qualifications nor the experience required.

The work as outlined requires the services of a job analyst, whose qualifications will be found in any literature on the subject of job analysis. If you have such an individual in your organization promote him to a staff position, as assistant to an executive who can and will give the analyst the necessary backing when required.

Perhaps the most economical plan is to engage the services of a managment engineer of good repute. His impartial point of view will be refreshing to the wide-awake executive and will more than offset any lack of inside knowledge of the particular organization. His recommendations may be radical, but the executive who follows them will find them to result in lasting saving effects.

Maintenance of Standards

It is wise to recognize that the idea of perfection is not involved in standardization. The standard method of doing anything is simply the best method that can be devised at the time the standard is established. Improvements in standards should be solicited and adopted whenever they are found. But to protect standards from changes that are not in the direction of improvement, certain safeguards must be provided. These safeguards protect standards from change for the sake of change. Among them are:

1 All standards must be carefully defined and described in writing
2 Any proposed change must be carefully scrutinized by those who framed the standard
3 Any change must be approved by the supervisor in charge
4 The changed standard, carefully defined and described in writing, must be followed.

Conclusion

A careful adherence to the foregoing program will provide real data for establishing and maintaining a sound wage-incentive plan. It will encourage "permanent prosperity" and give the organizations adopting it permanent reductions in expense.

Actual plans now in use, and which have resulted in large savings, are given in the Appendix. Its perusal is recommended, and if from it or from any other part of this paper a single executive finds assistance in solving his problems, the author will feel that his labor in preparing it has been well repaid.

Appendix No. 1

EXHIBIT I

At present we have the following operations on office equipment on a bonus basis:

Punching and Verifying Tabulating Cards (Hollerith). Time allowance is set per card. Some of the rates are:

0.0025 hr. per 20-hole card
0.0031 hr. per 30-hole card
0.0045 hr. per 45-hole card.

Employee brings cards punched to supervisor, who marks the task symbol on the time card. Timekeeper weighs the punched cards, converting weight into number of cards by multiplying weight in ounces by 11.8. Number of cards multiplied by task equals the time allowed. Employee receives 20 per cent of the time allowed as a bonus, provided the time allowed is not less than the time taken.

Example:

Employee punched 1 lb. 10 oz. of 30-hole cards.
26 oz. × 11.8 cards per ounce = 307 cards
307 cards × 0.0031 hr. = 1.0 hr. time allowed
20 per cent of 1.0 hr. = 0.2 hr., + 1.0 hr. = 1.2 hr.
Employee receives pay for 1.2 hr. while time taken was 0.9 hr.

Sorting Tabulating Cards. Time allowance is set per card. Rates are:

0.0035 hr. per card for less than 1000 sorted
0.0033 hr. per card for more than 1000 sorted.

Number of cards sorted is obtained by automatic counter on sorting machine.

Method of paying employee is identical with that for punching cards.

Invoicing. The time allowance for invoicing is based upon the Underwood fanfold typewriter. Four copies (original and three duplicates) are made. This type of invoicing is for goods being issued from the manufacturing operations to finished goods. Entries typed on invoice are invoice number at top, commission (4-digit), color (4-digit), piece number (2-5 digit), and yards (3-digit).

Time allowance:

0.016 hr. per invoice
0.0025 hr. per piece.

Production is counted by the timekeeper from a copy of the invoice. Bonus payment is based upon the size of job, that is, time

allowed divided by time taken equals the size of job. Payment of bonus is made on the clerical scale—10 per cent payment for 80 per cent job, and 0.5 per cent for each 1 per cent increase in size of job.

Typing. Although we have a time allowance for straight typing, we are not at present paying bonus.

The time allowances are:

0.0046 hr. per 6-in. line typed from copy
0.0053 hr. per 6-in. line typed from notes
0.0038 hr. per sheet if carbon copies are made
0.0067 hr. per page regardless of number of copies.

NOTE: Per sheet includes inserting and removing carbons; per page includes putting in and removing sheets from machine.

Addressographing. Time allowance for addressographing regular tabulating cards $3^1/_4$ in. × $7^3/_8$ in.:

0.435 hr. per job (this is allowed for each time the job is completed.)
0.00054 hr. per name per card addressographed.

Employee enters the job symbol and the number of cards addressographed on his production card. These entries are checked, to the order for the material, by the supervisor.

The time allowed is figured by multiplying the number of cards addressographed by the rate per card and adding the job allowance. Employee is paid bonus of 20 per cent of time allowed, as explained under Punching and Verifying Tabulating Cards, if the time allowed is not less than the time taken.

Multigraphing. Time allowance for multigraphing paper $8^1/_2$ in. × 11 in. of 13-lb. to 50-lb. weights. The rate includes placing the plate on the machine, inking, adjusting plate, running time, etc.

0.07 hr. per job
0.00025 hr. per sheet.

Employee enters the job symbol and the number of sheets multigraphed on his production card. These entries are checked, to the order for the material, by the supervisor.

Time allowed is figured and bonus payment made in exactly the same manner as described for addressographing.

Machine Calculations. The task for work on calculating machines is incorporated with other studies, and employee is paid a bonus according to the size of job accomplished.

EXHIBIT II

All of our graphotype work is done on bonus. A standard model G-3-D machine is used. The work includes receiving sheets with the necessary information, punching the name, address, policy number, agency symbol, premium-due date, and sometimes the amount of the premium. The information is put on three small plates which are fitted into one frame. When changes are made, usually only one of the three plates is punched anew. The allowance for punching a stencil without the premium amount is 1.05 min., and with the premium amount, 1.16 min. As the premium amount is punched on about 80 per cent of the stencils, the hourly output would be about 53 stencils. The average allowance for making changes is 0.400 min., and the output would be 150 per hour.

The punch operators in the Hollerith Division are working on bonus and are using the model 20 electrified machine. The work includes receiving information sheets, punching cards, and returning the work to the supervisor. The average allowance is 0.220 min. per card punched. This would give an hourly output of 273 cards.

In all of the divisions a daily record is kept of the number of various types of items handled by each person. This is usually the duty of the supervisor, and does not make additional personnel necessary, He also keeps a careful record of all time not spent on bonus work, keeping absent time, time spent on non-bonus work, and free time separate. Forms are provided for this. The bonus is figured and paid twice a month.

The basis on which bonus is paid is the percentage of efficiency, which is obtained by dividing the total minutes credited by the total minutes spent on bonus time. The clerk's credit is from two sources —number of units produced multiplied by rate in minutes per unit, and a standard allowance per session for personal time, cleaning machines, getting supplies, etc. The actual bonus time is the number of minutes in the period less minutes not spent on bonus. If the percentage of efficiency is above 70 per cent, the clerk is entitled to such percentage of her salary in bonus as her efficiency exceeds 70 per cent; that is, 85 per cent efficiency gives a clerk in bonus 15 per cent of her salary for the time worked. A typical bonus calculation would be as follows:

Minutes credit for production	3400		
Minutes credit for standard allowance	340		
Total minutes credit	3740	$\frac{3740}{4400}$ = 85%	efficiency
Total minutes in period	4500		
Minutes deducted	100	Less 70	
Total minutes bonus time	4400	15% bonus	

(Salary per minute)	×	(Minutes bonus time)	×	(Per cent of bonus)	= bonus amount
0.007575	×	4400	×	0.150	= $5.00

Penalty for errors may be a deduction from the bonus money earned, the amount per error being enough to make the clerk feel his loss through inaccuracy; or the penalty may be a loss of units of work on which credit is based. It has been our experience that the bonus ultimately increases accuracy.

An organization working at ordinary efficiency can expect about a 30 per cent reduction in personnel by the installation of a bonus.

Additional benefits of the bonus system are (1) a complete record of what each clerk is doing; (2) a tangible recognition of a clerk's superiority which cannot be considered in the regular salary; (3) longer service and greater income for the better employees, and the elimination of the poorer ones, as the aggregate saving of time enables us to decrease the staff; and (4) greater ease of supervision.

EXHIBIT III

We have measured output and pay and an incentive wage on billing-, calculating-, and typewriting-machine operations as they are used in the billing division of the customers' accounts departments.

Billing Operations

Machines Used: 27 style 2700 Burroughs public-utility billing machine (16 bank)
2 style 131700 Burroughs public-utility billing machine (17 bank)
(The latter machines are used for accounts which require a greater totalizing capacity, but otherwise are essentially the same as the larger group.)

Unit of Measurement: One complete bill.

Standard of Production: 270 units per hour, which is rated as 100 per cent production.

Operators must attain the standard production of 270 units per hour or 100 per cent before the wage incentive is applied.

For each per cent attained over the standard, the operator receives as an incentive wage 1 per cent of her hourly rate earned as regular salary. To illustrate:

Employee's salary per month	$120.00

Hours to earn above, assuming a 30-day month with 4 Saturdays and 4 Sundays:

22 days of 7 hours	154 hours
4 days (Saturdays) of $4^1/_2$ hr.	18 hours
Total	172 hours
Rate per hour = $120 ÷ 172 =	$0.697
Actual hours worked	80
Standard hours allowed	90
Efficiency 90 ÷ 80 =	113%
Percentage of bonus for 113% efficiency	13%
Total wages for actual hours 80 × 0.697	$55.76
Incentive wage, $55.76 × 13 per cent	$ 8.25

Incentive wages are paid for work done on standard operations only. In the example the employee worked 80 hours on standard work; therefore the bonus is for 80 hours' production. Had she attained the same production for the entire month the incentive wage would be $15.60 and total earnings $135.60. Total earnings in example shown would be $128.25.

The example illustrates how the gross bonus is computed. A deduction is made for errors based on a sliding scale as follows:

Less than one (1%) per cent of error	$^1/_2$¢ per error
1 to 2% of error	1¢ per error
2 to 3 per cent of error	$1^1/_2$¢ per error
3 to 4% of error	2¢ per error
4 to 5% of error	3¢ per error
Over 5% of error	5¢ per error

Our billing operation calls for the production of approximately 900,000 bills per month. Before the introduction of the wage-in-

centive plan the average output for all operators was about 180 bills per hour with 35 operators employed. At the present time the average production for all operators is approximately 305 bills per hour with 21 operators employed.

Errors average less than 1.2 per cent per operator, while the average bonus is 13 per cent.

The average individual range of attainment for a monthly period is between a high of 166 per cent and a low of 65 per cent.

The operator making the low attainment of 65 per cent is classified as a student having been on the work only a short time.

We have two operators, who seem to be exceptionally adept at the work, both of whom average from month to month 160 per cent of the standard.

Production for the larger number in the group varies between 102 and 140 per cent of the standard.

Operators who cannot attain the set standard of 270 bills per hour, are, after a fair trial, either transferred to other work or discharged.

Calculating. This work consists of proving the results of the billing operation. It is primarily addition and the application of a formula to prove that the proper rates have been applied to the customers' bills. In effect two operations are included:

(*a*) Balancing bill register sheets
(*b*) Checking bills.

The standard applies to the combined operation.

Machine Used: Felt and Tarrant comptometer (8 bank).

Unit of Measurement: One bill (the same unit is used for all operations.)

Production Standard: (*a-b*) Combination operation, 625 bills per hour.

The incentive wage is computed in the same manner as outlined above for billing operations. This group handles the entire output of the billers, that is, approximately 900,000 bills per month, with the attendant register sheets. The introduction of the incentive wage has resulted in an increase in the average production from 104 to 121 per cent of the standard. Operators have decreased from 13 to 11.

Graphotyping. Work consists of making addressograph plates showing customer's name, address, and other information.

Machine Used: Addressograph Co. No. G3-keyboard graphotype.

Unit of Measurement: Embossing 1 complete plate.

Production Standard: 90 plates per hour.

The incentive wage is computed in the same manner as outlined above for billing operations.

The volume of work involved in this operation is approximately 350,000 plates per year.

There were four employees in the group before the introduction of the incentive-wage plan. Since that time production has increased from 92 to 115 per cent of the standard and the number of employees has been reduced to three.

EXHIBIT IV

1 *Billing Work.* Royal typewriting machines with special character keys are used. 50,000 key strokes per operator for an eight-hour day is considered 100 per cent of efficiency in performing this work. We use a Veeder-Root Cyclometer on our machines to record the number of key depressions made by each operator each day.

2 *Multigraph Work.* We use a Set-O-Type machine manufactured by the Typographic Machines Company, of Dayton, Ohio, to set up the type used in running the letters on the multigraph machine. The standard time that we have established on this work is 0.319 min. per line of type set and a constant time per letter of 5.50 min.

Multigraph Printing (Machine Model No. 36). We have both the hand-fed machines and automatically fed machines in operation. The standard time per sheet on the hand-fed machine is 0.0132 min., with a constant per order of 3.76 min. The standard time on the automatically fed machine is 0.0151 min. per sheet, with a constant of 3.76 min. per order. The time on the automatic machine is slightly more per sheet, yet of course it does not require the attention of an operator to keep it going, so that the saving in labor resulting from the use of an automatic machine is considerable.

3 *Mimeograph Work.* We use a model No. 78 Mimeograph machine for performing our mimeograph work. In establishing standards for the running of this work we have classified the work into two groups, one where the machine automatically inserts a blotter between each two sheets of material run, and the other where blotters are not used at all. The standard times for the first classification where the blotters are automatically inserted by the machine are:

1st speed of machine	0.0734 min. per sheet
2nd speed of machine	0.0685 min. per sheet
Constant time per order	5.50 min.

The standard times for the second classification where blotters are not used at all are:

1st speed of machine	0.0392 min. per sheet
2nd speed of machine	0.0344 min. per sheet
3rd speed of machine	0.0305 min. per sheet

The constant time per order is 5.12 min. We have a standard on each of the three different speeds inasmuch as it is found that certain classes of work can be run at a faster speed than can others.

4 *Cutting Manila Stencils.* We use a Royal typewriting machine in cutting these stencils. This machine is a regularly equipped correspondence machine. We have two different classifications of this work, one where the address is composed of three lines without a code number, and the standard time for this class of work is 0.517 min. per stencil. The other class of work is identical with the first, with the exception that there is a code number composed of four digits which is placed at the left-hand corner of the stencil but on the same line with the city or state. The standard time for cutting a stencil of this classification is 0.550 min. The above times include the wetting of the stencils previous to inserting them into the machine for cutting.

5 *Addressing-Machine Work.* We use machines made by the Elliott Addressing Machine Company. These machines are hand-fed. Several different kinds of work pass through these machines, but the greater portion of it is 6 × 9-in. envelopes. The standard time allowed for addressing each envelope is 0.0383 min., with a constant per order of 2.53 min. We use these machines also to fill in doctors' names and addresses on certain detail slips that we send to salesmen. These slips are approximately 3 × 5 in. in size and are made up three in a group. The standard time for addressing these slips is 0.0498 min. per slip, with the same constant per order as indicated above.

6 *Key-Punching Work.* We use an electric key-punching machine manufactured by the International Business Machines Corporation. This machine is used to indicate the amount of sales made by each salesman to each of the customers called upon. These sales are represented by figures of four digits. The standard time that we allow for the automatic key-punching operation is 0.08661 min. per order, which represents one punched card. We use a master-control card in which is punched the territory number, salesman's number, and certain other miscellaneous information. This card of course controls the information that is automatically punched in cards that are run through this machine. The standard time allowed for punching the master control card is 0.1468 min.

7 *Posting Work.* We use a Dalton Multiplex machine in keeping a record of the amounts represented by the orders taken by our salesmen. The amount of each sale is posted on an individual card set up for each customer. The figures posted are composed of either three or four digits. The posting operation includes picking up the previous total, posting the amount representing the sale made, broken down into two parts, and then showing a new total on the sheet. The standard time for this operation is 0.240 min. per card posted.

8 *Typing Letters and Envelopes.* We use regular Royal typewriting machines in performing this work. There are several classifications of this work, one of which is copying letters of solid type on the regular letter-size forms, $8^1/_2 \times 11$ in. The standard time for performing this work is 0.2851 min. per line. 1 minute extra per letter is allowed if a carbon copy is required.

Addressing Envelopes: The standard time for addressing envelopes is 0.4277 min. per envelope, and the time for addressing postal cards is 0.5861 min. per card.

EXHIBIT V

The following bonus plan for key-punch operators was adopted after months of close study of past production records, and from time-study tests made with various operators for various periods.

A base salary is paid to all operators as follows:

$15 per week for beginners until they reach an output of 2800 cards per day
$16 per week for 2800 cards
$18 per week for 3000 cards.

After an operator reaches an average daily production of 3000 cards, with 1 per cent of error or less, she is paid 10 cents per 100 cards for all cards in excess of 3000.

Operators are given preference according to their production record. That is, No. 1 operator is given the first chance for continuous em-

ployment on card punching. This creates a competitive spirit among the operators. Those not engaged on card punching are paid the base salary only.

Errors. Deductions for errors are made at the rate of 2 cents each for all in excess of 1 per cent. No deductions are made from base pay. As a matter of fact, skilled operators average about three-fourths of 1 per cent, and deductions are seldom made except during the period when operators have reached the 3000-cards-per-day stage and have not yet attained the skill necessary to maintain higher production.

It should be mentioned here that our experience proves that increased accuracy and increased production on this kind of work run hand in hand. As production goes up, accuracy increases, or perhaps as accuracy increases, production goes up.

When the plan was started production of our best operators was about 3900 cards per day. Since the plan has been in operation, production has increased to as high as 5500 and 5700 cards per day for one week. This latter figure, however, was discouraged by the management, as it was noticed the operators were under a severe physical strain when working at this pressure. The average production today for our best operators is about 5500 cards. This is equivalent to a bonus of $2.50 in addition to the base pay of $3.00 per day.

The principal advantages of this plan are as follows:

1 Compensation based on actual production, resulting in better satisfied employees, as amount of earnings is limited only by inclination and skill of operators.

2 Provides an interest in the work due to competitive spirit developed.

3 Greater production at lowered unit cost.

4 Reduces training expense of new operators due to decreased turnover.

5 Improves attendance records as absence reduces earning power.

6 Production is more uniform as there is constant incentive for greater production.

7 Aid to office management.

Additional Aids to Production. At the same time the bonus plan was introduced, the electric key-punch machine was also adopted. This machine is doubtless entitled to some credit for increased production. The manufacturers claim 10 per cent increase in production. As our gross increase is about 40 per cent, we credit the bonus plan with an increase of 30 per cent.

Comptometer Operators' Incentive Plan. About two years ago we were faced with the problem of obtaining greater production from our comptometer operators on a certain class of work. We had been experimenting on various methods of getting increased output. Production and error records for each worker had been maintained and published in the hope that these would inspire the operators to greater effort.

Based on these records, flat salary increases had been made within certain broad production ranges. However, it was observed that while periodic salary increases had an immediate effect on increased production, the increased production was not maintained. This seemed to prove that the flat salary plan did not provide a sufficient incentive to constant high production.

After careful study, which incidentally had been going on for a period of two years, we worked out what we felt was a satisfactory day's production and for which we were willing to pay $3. This daily rate has no bearing whatever on the wage rates existing in this city. It is merely a base on which to calculate earnings for production in excess of the required minimum.

Our plan calls for a minimum production of 10,300 items per eight-hour day. No deduction is made for failure to reach this figure as it is not a difficult goal to attain. It usually takes a beginner three or four months to reach this production.

As soon as an operator maintains this rate of production for a period of two weeks, she is placed on the flat base rate of $3 per day. In addition she is paid $0.0341 per hundred items for all in excess of 10,300 per day.

A deduction of 2 cents each is made for all errors in excess of 1 per cent. By making a rather liberal allowance for errors, much clerical accounting work is avoided.

This plan has been in use for over two years and has been very successful. Production has increased from a daily average of 13,300 items for all operators to the present figure of 19,000 items per day for all operators.

Prior to introduction the daily average of our best operator was 6724 per day and the present average per day for the best operator is 20,000 items per day.

The error rate is now 0.446 items per 100, or considerably less than half what it was formerly.

It is our belief after trying both methods of production control that far better results in every way will be obtained from a good incentive plan than can be secured with the very best kind of "supervised" production, and with much less expense on the part of the management. Our supervision is almost automatic.

EXHIBIT VI

Comparison of Salary and Incentive Plans as Used in the Customers' Accounts Division

Graphotype. Until May, 1925, our graphotype operators were on a salary basis of approximately $25 per week. The monthly average of plates embossed per operator was approximately 7000. In June, 1925, the incentive plan was inaugurated with the following immediate results. The June figure showed an increase in plates embossed to approximately 8000 per operator, with an error percentage of 4.8 per cent and a wage scale of $24 per week. The July, 1925, figure showed a further increase in plates embossed to approximately 8500 per operator with an error percentage of 5.5 per cent and a wage scale of $25 per week. It will of course be understood that the wage scale is based on the number of plates embossed and the number of errors. Our error percentage showed a sharp decrease from this point on, while the average number of plates embossed per operator increased. Our figures at the present time, and these figures are just average, show approximately 9500 plates embossed per operator per month, with an error percentage of approximately 1.5 per cent and a weekly wage scale of $27.

The following figures reflect the yearly saving made by the introduction of the incentive plan:

Salary Plan

Plates embossed (number embossed in 1929)	310,000
Percentage of errors	5
Total labor cost	$5,096.00
Labor cost per 100 plates	$1.64

Incentive Plan

Plates embossed	310,000
Percentage of errors	1.5
Total labor cost	$3,741.00
Labor cost per 100 plates	$1.21

It is interesting to note the drop in percentage of errors, and also that the saving in labor cost is approximately 27 per cent.

Billing. The incentive plan has been in effect in our billing room about 10 years. This plan when first introduced paid a maximum of $27 per week. Since that time the maximum wage has been increased to $35 per week. Comparative figures are herewith given, showing the pre-incentive figures as compared with the present figures.

Pre-Incentive Plan

Number of bills rendered	1,385,791
Percentage of errors	4
Total labor cost	$29,900.00
Labor cost per 100 bills	$2.16

Incentive Plan

Number of bills rendered	2,626,330
Percentage of errors	1.3
Total labor cost	$42,660.00
Labor cost per 100 bills	$1.62

The incentive plan, as usual, resulted in a decrease of the number of errors and in a 30 per cent saving in labor cost. Before its adoption the number of bills rendered per hour was 53; after adoption the number was 99.

GRAPHOTYPE PLATE-EMBOSSING WAGE SCHEDULE

(General Accounting Department, Customers' Accounts Division)
Effective June 1, 1925

Points per month	Wage per week	Points per month	Wage per week
5000	$18.00	10,000	$28.00
6000	20.00	10,500	29.00
6500	21.00	11,000	30.00
7000	22.00	11,500	31.00
7500	23.00	12,000	32.00
8000	24.00	12,500	33.00
8500	25.00	13,000	34.00
9000	26.00	13,500	35.00
9500	27.00		

(*a*) Embossing of three-line plates to be counted as one point for each plate.

(*b*) Embossing of four- or five-line plates to be counted as one and one-half points for each plate.

The number of errors are to be taken into account and to be deducted from operators' total points according to the following schedule.

No. 1—Errors made on three-line plates: Deduct five points for each plate.

No. 2—Errors made on four- or five-line plates: Deduct ten points for each plate.

Wage rates to be adjusted monthly and to be effective the second Monday of each month.

Agreed that if the 400- or 900-mark is passed, the nearest even figures of scale will be allowed.

ELLIOTT-FISHER MACHINE-BILLING WAGE SCHEDULE

(General Accounting Department, Customers' Accounts Division)
Effective March billing, 1925

Points per month	Wage per week	Points per month	Wage per week
6,500	$20.00	10,500	$29.00
7,000	21.00	11,000	30.00
7,500	22.00	11,500	31.00
8,000	23.00	12,000	32.00
8,500	25.00	12,500	33.00
9,000	26.00	13,000	34.00
9,500	27.00	13,500	35.00
10,000	28.00		

The number of errors are to be taken into account and to be deducted from operators' total points according to the following schedule:

No. 1 Class of Error. Billing on wrong billheads or ledger records: Deduct 250 points for each error. Failure to clear machine, duplicate billing and incorrect subtraction: Deduct 100 points for each error.

No. 2 Class of Error. Incorrect totals on bottom of balance sheets: Deduct 50 points for each error.

No. 3 Class of Error. Writing over figures and failure to type in headings on bills or ledger records when blanks are used: Deduct 10 points for each error.

No. 4 Class of Error. Errors in spacing, running bills together on balance sheets, clerical errors of extensions, errors on statements, failure to leave proper spacing to facilitate count of customer: Deduct 5 points for each error.

Work done on Elliott-Fisher and "Ditto" machines to be rated as follows:

Residence billing and all overdue statements run on "Ditto" machines: One point each.

Commercial and disconnect billing, are to be counted as two points for each bill, as this work is very much slower than residence billing: Two points each.

Steam, weekly, special, municipal, sign, creamery, and deferred billing, also typing of merchandise and regular overdue statements are to be counted as three points for each bill or statement. It takes three times as long to bill this special work as residence billing: Three points each.

Primary and Energy Power Billing. Typing of weekly, energy, steam and special municipal overdue statements are to be counted as 5 points each, due to a great share of statements having many balances to be typed on. Five points each.

When the 400- or 900-mark is passed, the even figure of 500- or 1000-step of the rate scale is to be allowed.

Adding the points made on special work to total points made on regular work will increase the production per machine, as it will have a direct bearing on the operator's wage.

The above schedule will eliminate lost time and increase production, efficiency, and accuracy, as the application must be even closer than heretofore.

EXHIBIT VII

ACCOUNTING DEPARTMENT, METER-READING DIVISION

Comparative Report of Costs and Averages

Unit cost	Incentive-wage plan, Dec., 1929	Regular wage plan, Dec., 1922	Per cent or increase of Decrease
Regular readings	0.0234	0.0278	15.8
Skip readings	0.0729	0.0963	24.3
Rereads read	0.0479	0.0852	43.8
Special readings	0.1924	0.2982	35.5
Total readings	0.0277	0.0371	25.3
Bills delivered	0.0080	0.0099	19.2
Averages:			
Regular readings	399	324	23.1
Skip readings	136	99	37.2
Rereads read	194	114	70.1
Special readings	46	43	6.9
Bills delivered	1034	782	32.2
Wage per day per man	$7.04	$5.47	28.8
Employment Bureau record of labor turnover	1%	20%	

The differential is approximately the same for each month.

Included in the above costs are labor, supervision, automobile expense, and all supplies, such as stationery, flashlights, batteries, shoe and shoe repairs.

Meter-Readers' Wage Schedule (Effective June 8, 1923). The following scale of wages will be effective the first Monday in each calendar month, as of the preceding calendar month's record.

No. of Readings per month	No. of skips	No. of rereads	Wage per hour, cents	Average readings per day	Unit cost
6,900	550	69	55	300	0.0173
7,600	600	76	60	330	0.0172
9,000	700	90	65	390	0.0157
9,700	775	97	70	422	0.0157
10,400	825	104	75	452	0.0157
11,500	900	115	80	500	0.0151

Penalties

1 Deduct 10 readings from total for eack skip or reread in excess of number allowed as above.

2 Deduct 50 readings from total for each day's work counted incorrectly.

3 Deduct 50 readings from total for each meter in route not read because of not finding card.

4 Deduct 50 readings from total for miscellaneous errors in each day's work.

NUMBER OF EMPLOYEES AT EACH RATE, JANUARY 1, 1930

No. of employees	Rate per hour, cents
2	55
4	60
1	65
5	70
5	75
27	80
Total 44	

Wage Schedule, Bill Delivery (Effective Dec. 13, 1923). The following scale of wages will be effective the first Monday in each calendar month, as of the preceding calendar month's record.

Rate per hour, cents	No. of bills delivered per month	Average per day	Unit cost
55	18,975	825	0.0062
60	21,275	925	0.0061
65	23,575	1025	0.0060
70	25,875	1125	0.0059
75	28,175	1225	0.0058
80	30,475	1325	0.0057

Penalties

1 Deduct 10 bills from total for each bill returned to mail, over 2 per cent.

2 Deduct 50 bills from total for each bill not delivered according to instructions.

NUMBER OF EMPLOYEES AT EACH RATE, JANUARY 1, 1930

No. of employees	Rate per hour, cents
0	55
0	60
1	65
1	70
5	75
Total 7	

Machine Meter Reading-Posting Wage Schedule (Effective Nov. 5, 1923). The following scale of wages will be effective the first Monday in each calendar month, as of the preceding calendar month's record:

No. of readings posted per month	Wage per week	Unit cost
30,000	$18	0.0025
32,500	20	0.0025
35,000	21	0.0025
37,500	22	0.0024
40,000	23	0.0023
42,500	24	0.0023
45,000	25	0.0023
50,000	27	0.0022
52,500	28	0.0022
57,500	30	0.0021

Penalties

1 Deduct 25 postings from total for each reading copied incorrectly.

2 Deduct 50 postings from total for each reading posted, not spaced correctly.

3 Deduct 50 postings from total for each reading not posted in proper column.

4 Deduct 50 postings from total for each meter-reading book not dated correctly.

5 Deduct 50 postings from total for each meter-reading book not counted correctly.

NUMBER OF EMPLOYEES AT EACH RATE, JANUARY 1, 1930

No. of employees	Rate per week
1	$18
1	23
1	27
2	30
Total 5	

Auditors' Wage Schedule (Effective Dec. 31, 1929). The following scale of wages will be effective the first Monday in each calendar month, as of the previous calendar month's record.

No. of points per month	Rate per week	Unit cost
60,000	$30	0.0020
64,000	32	0.0020
66,000	34	0.0021
69,000	36	0.0021
73,000	38	0.0021
78,000	40	0.0021
84,000	42	0.0020
91,000	44	0.0020
99,000	46	0.0019
108,000	48	0.0018
118,000	50	0.0017

Residence account	1 point
Commercial account	3 points
Energy light and power account (over 10 kw.)	4 points

Penalties

Errors	Points
Watt-hour constant	1000
Demand constant	1000
Incorrect base	500
Incorrect service charge	500
Meter not reread or investigated	500
Rereads and investigations not necessary	250
Incorrect subtraction	250
Readings posted to wrong meter	200
Failure to issue credit notice	200
Credit notice issued in error	200
Billed for less than 16 days	200
New and turned sheets	200
Omission of stamps	200
Failure to order larger or smaller demands	200
Failure to rule out reading	200

EXHIBIT VIII

In general, because of the switching of employees from one type of work to another, we measure our work in standard minutes or points, which gives us the necessary common denominator.

Our task is expressed in per cent, in order to make comparisons between dissimilar jobs and departments possible. We prefer the per cent method of expression to other methods, such as "point-hour" etc., because it is familiar to all interested people.

Our bonus payment starts at 70 to 75 per cent of task. One hundred per cent is a goal to be attained and slightly exceeded continuously by the average of the group on bonus. We expect the exceptional person to attain 120 to 125 per cent of task.

Our rate of payment is ²/₃ to ³/₄ per cent of a base salary for each 1 per cent improvement (above starting point) on the bonus scale.

BONUS PLAN FOR TYPISTS IN THE CORRESPONDENCE AND MAIL-ORDER DEPARTMENTS OF THE B. OF A.

Approved by B. of O. 11/8/29

The bonus plan which is outlined below (as recommended for adoption by the Operating Department and the Planning Department) was approved by the B. of O. on Nov. 8, 1929.

The plan is to replace the increasing salary scale plan which until recently has been operating in the above departments.

The essential features of the bonus plan are:

A. It will be an individual bonus; i.e., each person's earnings depends upon *her own* rate of production only.

Employees whose symbols are BCT and BMT are regularly included in the plan. Any other typists doing bonus work will be paid a bonus (if earned) for the time spent doing such work.

B. *Bonus Task or 100 Per Cent Efficiency.* An average of 60 points of work produced per hour or 2880 points per full 48-hour week.

C. *Bonus Starting Point or 70 Per Cent Efficiency.* 42 points of work produced per hour or 2016 points per full 48-hour week.

D. *Bonus Payment.* 12 cents for each 25 points produced over the minimum amount required for the week.

Time spent in other sections or divisions on non-bonus work is not included when calculating the required production per week; i.e., if a typist spends 40 hours doing bonus work and 8 hours doing non-bonus work, her required production for that week would be 40 × 42 points per hour = 1680 points of work.

No bonus is paid for time spent on non-bonus work.

E. *Record of Production and Time.* The individual daily card used at present for production and time records will be continued. The following data are recorded on this card:

1 For Bonus Work: Class of work and number of pieces of each class
2 For Non-Bonus Work: Kind of work done and number of pieces if possible
3 Time work was started
4 Time work was finished.

All work is counted and distributed to each typist by a distributing clerk. The distributing clerk records this count on the daily card. Work which is done over because of errors on the part of the typist is not recounted.

The detailed record collected on this card is required for operating purposes within the department and *not for bonus records.*

For bonus purposes the Statistical Division of the B. of A. will summarize this data as follows for each person:

1 Multiply the total number of pieces of each class of work by the point allowance per piece (for that class of work) to get the number of *points* produced for each class. Add all classes to get total point allowance for the day
2 Get total hours spent on bonus work
3 Get total hours spent on non-bonus work.

This summary data will be posted to a weekly individual time and production card by the Statistical Division. These weekly cards will also state the type of work done for which non-bonus time is claimed.

These weekly cards will be forwarded to the Controller's Office for the purpose of calculating the bonus. The original records from which the data was summarized are subject to audit by the Controller's Office at any time.

(NOTE: Non-bonus time includes only such time spent *doing work* for which there is no point allowance, such as work in another department or division. All other allowances are provided for in the Standards—see Planning Department memo dated 10/28/29.)

The following (Paragraphs F, G, H, and J) to be done by the Controller's Office:

F. *Analyze the Weekly, Individual, Time, and Production Cards.* The Controller's Office will total each employee's weekly time card to determine—

1 Total hours on bonus work
2 Total hours on non-bonus work.
(The total of 1 and 2 must be checked with Salary Office and overtime figures.)
3 Total points produced.

G. *Calculate the Bonus.* The following steps are necessary to calculate the bonus each week:

1 Multiply hours on bonus work that week by 42 points per hour to get the minimum number of points required
2 Subtract the minimum points required as found in (1) from the Total Points produced (F-3)
3 Divide the difference by 25 and multiply by 12 cents.

H. *Calculate the Efficiency of Each Person.* The following steps are necessary:

1 Divide the total points produced (obtained in F-3) *by* the total hours on bonus work (F-1) times 60 points per hour.

J. *Present Summary of Data.* The Controller's Office will furnish the following data for the week for each person to the Operating Department (2 copies), the Budgeting Office, and the Planning Department:

1 Total points produced (F-3)
2 Total hours on bonus work (F-1)
3 Minimum required points (G-1)
4 Number of points produced over minimum (G-2)
5 Amount of bonus earned (G-3)
6 Efficiency of each person (H-1)
7 Total hours on non-bonus work (F-2)
8 Nature of non-bonus work done or department or division worked for (from weekly cards).

K. *Schedule of Bonus Payments for Salary Office.* The Con-

troller's Office has given two copies of the summary data (see Par. J)to the Operating Department. One of these copies must be initialed by the department manager and the assistant general manager, and then forwarded to the Salary Office by the Operating Department.

L. *The Operating Department* will present the data supplied by the Controller's Office to the typists included in the bonus.

M. *The Budgeting Office* will determine a weekly unit cost and savings for BMT and BCT employees as follows:

1 Determine total base salary cost for the week, as follows:
   - *a* Get proportion of hours spent on bonus work to hours spent on non-bonus work (F1 and F2)
   - *b* Get total base salary (not including bonus) paid to BMT and BCT symbols (salary comparison sheets)
   - *c* Multiply base salary (*b*) by ratio determined in (*a*)

2 Add total bonus earned for week (total of J-5 above)

3 Divide total salary (base salary plus bonus) for the week by the total points produced for the week (total of J-1 above). This is the unit cost

4 Subtract the unit cost thus obtained from the past unit cost (see next paragraph) and multiply by total points produced for the week (total of J-1 above) to obtain total savings for the week.

N. *Past Unit Cost.* In order to obtain a reliable record of future savings, it is necessary that the past unit cost used as a basis for measuring savings be a definite and unchallenged figure.

It is recommended, therefore, that the individual daily time and production records covering the work of all BMT and BCT employees for the four weeks ending 11/9/29 be analyzed by the B. of A. Statistical Division in the exact and complete manner outlined in this report. The average unit cost thus obtained for the four weeks noted shall be accepted as past unit cost. The Statistical Division shall report this past unit cost to the Budgeting Office.

It shall be understood, however, that this cost will be considerably lower than the former cost would have been since this department has been operating under a type of incentive for a period of about two years. Therefore any future savings must be made over and above a considerable previous improvement.

The various classes of work and the corresponding symbol and point allowance per piece are as follows:

Class of work	Symbol	Time or point allowance per piece
Paid mail register entries	PMR	0.35
Addressing envelopes, typing stubs (M.O.D.)	A	0.37
Enter-ups, C.P.I. record cards, form 2283	EU	0.43
Form letters filled in (one, two, and three words)	FL 1	0.75
Form letters filled in (Controller's Office forms) Copy-offs	FL 2	1.83
Paid mail-order cards	PMO	0.87
Transcripts M.O.D.	T	0.94
Order backs (Elliott-Fisher)	FL 3	1.74
Form letters typed (tallies up to 10 lines, bills up to 10 lines, 2nd complaint transcripts)	FLT 1	2.08
Charge tickets (Royal Manifold) form letters typed, bills over 10 lines and tallies over 10 lines	FLT 2	3.47
Reports Class 3	R 3	0.42 per sq. in.
Reports Class 2	R 2	0.47
Reports Class 1	R 1	0.58

The Clerical Costs involved are:

B. of A.—Same as at present.

Controller's Office—Same as for the packers' bonus recently approved. This was estimated by the Controller's Office as a maximum of two days, representing a clerical cost of $6.

The bonus rate provides for a split of labor savings (above bonus starting point) of approximately 50 per cent to the organization and 50 per cent to the employee. In this respect it follows the basic plan used for the recently approved packing unit and the accounts payable bonuses.

It is management's function to see that any person who is hired at a higher-range salary reaches the minimum production and approaches the task in a reasonable length of time.

Special Penalties: 1 All incorrect work must be done over and is not recounted.

2 For 10 errors per week, no additional penalty.

3 For every error over 10, one unit of work will be subtracted from total production (this applies to both kinds of work).

Equipment: Comtometer and Mercedes machines.

Duties: Comptometer Operations:

(*a*) Calculate *cost* and *selling* totals on invoices, shorts, overs, returns, markdowns (etc.), mdse. transfers, mfg. dept. sales, special purchases, journal transfers, and charges. (Charges are made out by the comptometer operators)

(*b*) Add discounts on individual vouchers and obtain total discount on all vouchers for comparison with bookkeepers' total. It is estimated that this work takes approximately 15 min. per day for each first figurer. Each first figurer is given approximately an equal number of vouchers to do. These are not counted in the person's production, an allowance having been made for this work when setting up the production standards.

Mercedes Operations:

Calculate *discount*, amount of anticipation, and per cent mark-on for items listed in (*a*)

Units Counted: All items listed in (*a*) above are counted in three separate groups as follows:

(*a*) Invoices
(*b*) Charges[1]
(*c*) Other items (shorts, overs, returns, markdowns (etc.), merchandise transfers, mfg. dept. sales, special purchases, and journal transfers).

Only 1/2 unit is allowed for each charge as this involves only one-half as much work as in the case of other units.

Where Count Obtained: Each person counts her own production. Total of all persons can be checked with total of all second figurers.

Past Records: Average production (7th through 17th wk. Spring, 1929).

	Comptometer	Mercedes
Units per day	402	637
Maximum production, single day	729	2130

Past *actual* salary range, $18 to $25

Past average salary, $22.60

Maximum salaries paid during period Feb. to Oct., 1929:

1 person	$27
1 person	$29

Cost per 100 units, Spring, 1929, $1.531

$$\left[\begin{array}{l} 1 \text{ day} \div \frac{402}{637} \text{ days} = 1.631 \text{ days for 402 pieces} \\ \$22.60 \div 6 \text{ (days)} \times 1.631 \text{ (days)} \div 4.02 \text{ pcs.} = \$1.531 \text{ per 100 pcs.} \end{array}\right]$$

Special Penalties: Deduct 20 units for every error during week. (This is approximately 5 cents per error.)

Equipment: Comptometer (also 1 Electric Burroughs on trial).

Duties: Refigure all work calculated by 1st figurers except percentage work on which is to be checked by inspection and refigured if it looks wrong. All errors found are to be noted and the items returned to the first figurer for correction.

Units Counted: Same items counted by first figurers but divided into four groups as follows:

a Invoices
b Charges (full credit given)
c Markdowns, etc.
d Other items (shorts, overs, returns, mds. transfers, mfg. dept. sales, special purchases, and journal transfers).

Where Count Obtained: Each person makes own count. Total for all second figurers can be checked with first figurer's count.

PLANNING DEPARTMENT

October 23, 1929

CONTROLLER'S OFFICE—ACCOUNTS PAYABLE BONUS

Name of Job: 1st Figurers — No. of People 10

Efficiency		Production: Comptometer Units per day	Production: Comptometer Units per week	Production: Mercedes Units per day	Production: Mercedes Units per week	Earnings: Salary range	Earnings: Assumed average salary	Earnings: Bonus earned	Unit Cost: Cost per 100 units at Average salary Spring, 1929	Unit Cost: Cost per 100 units at Average salary October, 1929
Par	125%	700	...	1785	...	.....	.....	.....	.....	....
Task	100%	560[1]	3360	1428[a]	8568	$21.67 to 28.67	$25.67	$3.67	$0.764	....
Starting pt.	75%	420	2520	1070	6420	18.00 to 25.00	22.00	0.00	0.873	....

[a] Combined unit for Comptometer and Mercedes operations.

NOTE: *Re* range of $18 to $25 in base salary: Range made as large as this to take care of two different kinds of help which may be hired; i.e., beginners at $18, and experienced operators nearer to $25.

PLANNING DEPARTMENT

October 23, 1929

CONTROLLER'S OFFICE—ACCOUNTS PAYABLE BONUS

Name of Job: 2nd Figurers — No. of People 3

Efficiency		Production Units per day	Production Units per week	Earnings: Salary range	Earnings: Assumed average salary	Earnings: Bonus earned	Unit Cost: Cost per 100 units at average salary, Spring, 1929	Unit Cost: Cost per 100 units at average salary, October, 1929
Par	125%	1250	....	.....	....	....	....	....
Task	100%	1000	6000	.....	$30.34	4.34	$0.506	....
Starting pt.	75%	750	4500	$24—27	26.00	0.00	0.578	....

Past Records: Average production (7th through 17th wk., Spring, 1929).

Units per day	812
Maximum production, single day	1238
Present actual salary range	$27–$30
Present average salary	$28.66
Cost per 100 units, Spring, 1929	$0.588

PLANNING DEPARTMENT

October 23, 1929

CONTROLLER'S OFFICE—ACCOUNTS PAYABLE BONUS

Name of Job: Control Sorter — No. of People 1

Efficiency		Production Units per day	Production Units per week	Earnings: Salary range	Earnings: Assumed average salary	Earnings: Bonus earned	Unit Cost: Cost per 100 units at average salary, Spring, 1929	Unit Cost: Cost per 100 units at average salary, October, 1929
Par	125%	2750	16,500	.....	....	....	....	....
Task	100%	2200	13,200	$16.58–19.58	18.08	2.58	$0.137	....
Starting pt.	75%	1650	9,900	14.00–17.00	15.50	0.00	0.157	....

Equipment: Sorting tub with flexifile—90 guides.

Duties: *a* Resorts invoices within each ledger group into five department groups. Also stuffs carbon sheets in couchers for voucher clerk. Also handles some returns for which there are no invoices. (Approximately 75 per day.) These are sorted like invoices. Also helps control clerk to learn control clerk's job. (This time included in standard.)

Units Counted: Invoices (shorts, overs, and returns are attached) only. An allowance has been made in our standards for those special returns for which there are no invoices.

Where Count Obtained: Receiving Department checkerboards.

Past Records: Average production (7th through 17th wk., Spring, 1929).

Units per day	1470
Maximum production, single day	2634
Present salary	$15
Max. salary during above 11-wk. period	$17
Cost per 100 units, Spring, 1929, $0.17 based on $15 salary	
Cost per 100 units at same rate of production if salary were $17	$0.193

(This will be salary of new person now on this job. Higher salary paid because this person to train to take over *control clerk's* work in emergency.)

PLANNING DEPARTMENT

October 23, 1929

CONTROLLER'S OFFICE—ACCOUNTS PAYABLE BONUS

Name of Job: Control Typists — No. of People 2

Efficiency		Production Units per day	Production Units per week	Earnings: Salary range	Earnings: Assumed average salary	Earnings: Bonus earned	Unit cost: Cost per 100 units at average salary, Spring, 1929	Unit cost: Cost per 100 units at average salary, October, 1929
Par	125%	1600	....	.....	....	....	....	....
Task	100%	1280	7680	21.34– 24.34	$23.34	$3.34	$0.304	....
Starting pt.	75%	960	5760	18.00– 21.00	20.00	0.00	0.347	....

Equipment: Remington-Wahl bookkeeping machine.

Duties: Types debit and credit invoice register sheets by ledger, subdivided by debits and credits and further subdivided into 5 departmental groups. Obtains subtotal for departmental groups and the grand total for all departments in the ledger. Items typed are invoices, shorts, overs, returns, transportation ticket (where vendor pays), and charges.

Units Counted: Invoices (including special pay invoices which have already been paid) shorts, overs and returns, transportation tickets (where vendor pays) and charges.

Where Count Obtained: From typewritten (invoice register sheets) person makes own count.

Past Records: Average production (7th through 17th wk., Spring, 1929).

Units per day	985
Maximum production, single day	1609
Average salary above 11 weeks	$24.50
Actual salary range, Feb. to Oct., 1929	$20–$25
Present average salary (10–15–19)	$23
Present salaries (10–15–29)	$22 and $24
Cost per 100 units, Spring, 1929	$0.424

NOTE: *Re* penalties: This person's errors would delay the voucher clerk when proving figures. Therefore voucher clerk will bring more pressure to bear on control typist than any arbitrary penalty would be able to do.

PLANNING DEPARTMENT

October 23, 1929

CONTROLLER'S OFFICE—ACCOUNTS PAYABLE BONUS

Name of Job: Voucher Clerks — No. of People 5

Efficiency		Production Units per day	Production Units per week	Earnings: Salary range	Earnings: Assumed average salary	Earnings: Bonus earned	Unit cost: Cost per 100 units at average salary, Spring, 1929	Unit cost: Cost per 100 units at average salary, October, 1929
Par	125%	675	....	.....	....	....	....	....
Task	100%	540	3240	$26–$29	28.00	$4.00	$0.864	....
Starting pt.	75%	405	2430	22– 25	24.00	0.00	0.988	....

Equipment: Remington-Wahl bookkeeping machine.

Duties: Sorts invoices, etc., by vendor, types voucher for each vendor, and types name and address on check portion of voucher.

Units Counted: The unit is the number of entries on all vouchers (not number of vouchers). Therefore the units counted are all invoices, shorts, overs, returns, transportation tickets (where vendor pays) and charges.

Where Count Obtained: Each voucher clerk counts her own production. The total must equal the control typists' total less the special pay invoices (already paid).

Past Records: Average production (7th through 17th wk., Spring, 1929).

Units per day	399
(Average of 399 = 366, 384, 388, 420, and 438 for five individuals)	
Maximum production, single day	762
2nd highest production, single day	669
Average salary, above 11 weeks	$24.60
(Salaries = $21, $24, $24, $24, and $24)	
Maximum salary during period Feb. to Oct., 1929	$26
Cost per 100 units, spring 1929	$1.03

NOTE: *Re* penalties: Voucher clerk must prove her own figures. If incorrect, must find error on own time. No additional penalty necessary.

Equipment: Remington-Wahl bookkeeping machine.

Duties: Enters debits and credits on vendor's account. Sets up cash and discount figures.

Units Counted: All invoices, shorts, overs, returns, transportation tickets (where vendor pays) and charges plus special pay invoices (already paid) plus number of vouchers (for cash entries).

Where Count Obtained: Each bookkeeper counts her own production. Checked with voucher clerk's records and check register's records.

Past Records: Average production (7th through 17th wk., Spring, 1929).

Units per day	612
Max. production, single day	1064
Average salary—above 11-week period	$26.60
Actual present salary range	$25–$29
Maximum salary, Feb. to Oct., 1929	$29
Cost per 100 units, Spring, 1929	$0.724

Spring, 1929—7th through 17 weeks

Average prod.	Sal. paid
552	$20
570	26
573	25
660	26
705	27

Equipment: Defiance check writer.

Duties: Record amount of money on checks (embossed).

Units Counted: All regular vouchers listed on check register sheet plus special pay vouchers (to be paid) received from special pay clerk.

Where Count Obtained: Total of check-register typists plus total from special pay clerk's check register sheet.

Past Records: Average production (7th through 17th wk., Spring, 1929).

Unit per day	934
Maximum production, single day	1609
Time-studied production (Using average times + 10% fatigue and 395 min. working time)	1790
Average salary during above 11-wk. period	$20
Present salary	$20
Maximum salary, Feb. to Oct., 1929	$22
Cost per 100 units, Spring, 1929	$0.356

PLANNING DEPARTMENT

October 23, 1929

CONTROLLER'S OFFICE—ACCOUNTS PAYABLE BONUS

Name of Job: Bookkeepers — No. of People 5

Efficiency		Production Units per day	Production Units per week	Earnings: Salary range	Earnings: Assumed average salary	Earnings: Bonus earned	Unit cost: Cost per 100 units at average salary, Spring, 1929	Unit cost: Cost per 100 units at average salary, October, 1929
Par	125%	1000	6000					
Task	100%	800	4800	$27.33–32.33	$30.33	$4.33	$0.632	....
Starting pt.	75%	600	3600	23.00–28.00	26.00	0.00	0.722	....

PLANNING DEPARTMENT

October 23, 1929

CONTROLLER'S OFFICE—ACCOUNTS PAYABLE BONUS

Name of Job: Check Writer — No. of People 1

Efficiency		Production Units per day	Production Units per week	Earnings: Salary range	Earnings: Assumed average salary	Earnings: Bonus earned	Unit cost: Cost per 100 units at average salary, Spring, 1929	Unit cost: Cost per 100 units at average salary, October, 1929
Par	125%	1750	....					
Task	100%	1400	8400	21.26–24.26	22.76	3.26	$0.27	....
Starting pt.	75%	1050	6300	18.00–21.00	19.50	0.00	0.31	....

PLANNING DEPARTMENT

October 18, 1929

EXTRACT FROM BONUS PLAN FOR ACCOUNTS PAYABLE DIVISION OF CONTROLLER'S OFFICE

B *Production:* Production will be counted in units for each job but translated into "points" in order to provide a uniform measuring stick for different kinds of work.

A point equals the amount of work which should be performed in one minute when performed at a rate of speed which we consider to represent 100 per cent efficiency.

C *Bonus Task or 100 Per Cent Efficiency:* The bonus task equals 60 points produced for each hour worked and is considered to reach and exceed. We expect the average production on every job to be at least 100% or better after a reasonable period of time.

D *Bonus Starting Point or 75 Per Cent Efficiency:* In order to encourage employees to reach and exceed 100 per cent efficiency (they now average around 75 per cent), we shall start paying a bonus whenever a person's production exceeds a minimum efficiency of 75 per cent. To be 75 per cent efficient, a person must produce 45 points of work for every hour she works (on bonus work). This is the minimum requirement.

E *Bonus Payment:* This will equal a certain amount for every 100 points produced over the minimum requirement. The amount will vary with each job and will be high for higher-salaried jobs.

Appendix No. 2

PARTIAL LIST OF PUBLICATIONS OF THE AMERICAN MANAGEMENT ASSOCIATION

Job Analysis: — Annual Convention Series No.

"What's Ahead for Management," Lillian M. Gilbreth 40

"Improving Management Through Job Analysis," Harry A. Hopf 62

Measuring Office-Output Wage Incentives for Office Employees: — Office Executive Series No.

"The Control of Output in Offices," Wallace Clark 9

"Extra Incentive Wage Plans for Office Employees," F. L. Rowland and W. J. Harper 11

"Measuring Office Output: The Status of Measuring," Marion A. Bills 16

"Units of Measurement," Wallace Clark

"A Specific Case," A. S. Donaldson

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MAN-52-10

Management of a Large Plant: How to Retain the Advantages of the Small Plant

By A. B. REYNDERS,[1] SPRINGFIELD, MASS.

Experience shows that one man cannot efficiently supervise more than ten others. Each assistant should have definite duties and responsibilities in order to become a regular superintendent or foreman. A carefully planned organization with clearly defined duties for each position will accomplish much, but the selection of proper men is of great importance. The success of a small concern depends almost entirely upon its personnel. As the organization grows its functioning consumes more time, and a large corporation must function through written instructions. A large plant has the advantage of quantity production and can also obtain the advantages of the small plant by careful attention to details. The advantages usually considered as resulting from a small plant are quick action, low-production cost of small quantities, and close relationship of employee and employer. The paper discusses each of these advantages and outlines methods of obtaining them in large organizations.

THE sole object of any manufacturing plant is to make money by rendering a legitimate service. Some may think that they are in business to maintain a reputation, to produce wonderful engineering feats, to give employment to a small or a large number of employees, but in the final analysis, unless they are operating a charitable or a governmental institution, they must make a monetary return on the invested capital or else, ultimately, cease to do business. Whether a large or a small concern, this is true. How it is accomplished varies. In a small company, this responsibility is directly assumed by the owners. In a large concern, the owners, commonly called stockholders, are many, and the responsibility for results is delegated to an employed organization. The control or direction of this organization to obtain the desired results is known as management.

The form of an organization is of vital importance to its functioning. If it is not set up properly, the management will be inefficient. The larger the organization, the more necessary it is that all activities be covered and that the duties and responsibility of each individual in charge be definitely fixed. Overlapping of duties causes confusion, with resultant loss of time and costly errors.

A large manufacturing enterprise would do well to pattern its form of organization somewhat after the oldest organization in the world, the army. It has its line for fighting, its staff for advice and coordination, and its councils for specific tasks. Long experience has shown that one man can, with efficiency, personally supervise the efforts of not more than ten men.

In a large industrial corporation, the owners or stockholders elect a board of directors, the board of directors elects the officers, and the officers, in turn, appoint the managers, the supervisors, and so on down the line. Graphically, this may be described as an hourglass type of organization, starting with a large number of owners, concentrating in a chairman of the board or a president, and then expanding to cover various activities. In general, these activities are centered about three major divisions, selling, designing, and manufacturing. In addition, there are various allied activities such as the financial department, the legal department, the accounting department, the credit department, etc. This constitutes the line. Certain officers of the corporation, such as the vice-president in charge of manufacturing, require a staff of experts to advise the managers of the different plants or to coordinate their efforts. In addition, various committees are formed from time to time to perform certain functions, such as welfare committees, safety committees, etc.

Just as in the army, such an organization will be found to function best when one officer or supervisor personally directs not more than ten men. Here the author wishes to make a statement which has been the result of some years of observation. Every assistant should have definite duties and responsibilities. If he has duties assigned to him from time to time by his immediate superior, he either becomes a glorified secretary or else he assumes authority and runs the job. In both cases, he is a misfit. An assistant with definite duties becomes a regular executive, such as a superintendent or a general foreman. A carefully planned organization with clearly defined duties for each position will accomplish much, but the selection of the proper men is of the greatest importance. In fact, the success of a small concern depends almost entirely upon its personnel. Many a poor organization functions because of the high-grade men directing it.

From now on, the remarks will be confined to certain features of factory management only, with no attempt to cover all activities of the corporation. Such activities as executive control, sales, engineering, legal, research, etc., will be mentioned only briefly in relation to the works. However, before proceeding on factory management, it would be well to define what is meant by a *large* plant and what is meant by a *small* plant. Such terms as "large" and "small" are relative. For the purpose of this paper the number employed will be used as a basis for classifying a plant as large or small; a large plant having 1000 or more employees; less than 1000 employees being considered small. Also, to be concrete, the plant to be discussed will be considered as one manufacturing electrical apparatus, both in large and small quantities, and having as a maximum number of employees around 5000.

As soon as an organization grows in size, it begins to consume time in its functioning. This time-consuming propensity is the greatest objection to increasing the size of a plant. It is obvious that, when so many persons are employed, oral instructions cannot be followed without involving too great a hazard in execution. A large corporation is therefore compelled to function through written instructions. The customer's wants are usually determined and set down in "black and white," the engineers use these requirements as a basis for their drawings and specifications, and the factory works to the drawings and specifications in executing the work. The larger the company, the less value any oral instructions have. The result of this method of doing business is a definite understanding by the customer on what

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Contributed by the Management Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

he is to be given and an equally definite understanding by the manufacturer on what he is to furnish, but it has the disadvantage that it takes time. Not only is time lost, but expense is incurred for stationery, for typing, for transmitting from place to place, for recording, for filing, etc. This increases the overhead, the greatest bugbear of modern business management. Again, the executives in charge, being unable personally to handle the details, must depend on reports and records to reach decisions or to issue instructions. Additional paper work and more time are thus required, and up goes the overhead again. A small plant possesses a decided advantage in this respect. Now let a typical factory organization be taken and show how it functions.

Cost Accounting

As stated previously, the sole object of any manufacturing plant is to make money. To do this, it is essential that factory costs be known immediately after the apparatus is delivered. If this does not occur, estimates on new business are likely to be wild guesses. Factory costs are usually compiled by adding the cost of the material, labor, and overhead. Deviations from the allowed time and estimated materials which actually occur are treated as variances, and such variances are absorbed each month through the profit and loss accounts. Material costs are compiled from the drawings or the specifications, labor is obtained from the time cards of the workmen, and the overhead includes all expense, both labor and material, that cannot properly be charged direct to the order. It is the object of good management to reduce this item to a minimum, although it does not necessarily follow that low overhead means low cost. Usually the installation of labor-saving machines means an increase in overhead, but a decrease in the total cost. Sometimes labor and overhead are combined in one figure, and then designated as the department rate. This rate, multiplied by the "time taken," and the product added to the cost of the material, gives the factory cost under what is known as the standard cost system.

On the assumption that the designs as furnished by the engineering department are settled, it becomes the duty of the factory organization to keep the cost to a minimum by:

1 Purchasing material at the lowest market price to obtain the desired quality
2 Time study to reduce direct labor to a minimum
3 Budgeting to keep the overhead within definite limits.

It is the duty of the accounting department to maintain records of the results accomplished along these lines and to make concise but comprehensive reports so that the departmental heads can plan for corrections or improvements.

This department furnishes to the interested departmental heads a factory expense report. This form shows all the expense items, such as salaries and wages for foremen, for rate setters, for inspectors, defective work, depreciation, maintenance, etc., and the allowance for each item for the week, the month, and for the financial period, etc. Opposite each allowance is placed the actual expenditures or the amount spent in excess of the allowance. Such allowances are of little value unless they are rigidly adhered to. The original method of enforcing them was to permit no raises in salaries unless the budget figures were met. Later on, a bonus was offered if the budget figures were lowered.

Cost Reduction

It should be understood that a cost-accounting department is a recording department; that it does not reduce the cost, only calls attention to the facts as they have occurred. It is essential in this day of keen competition that aggressive cost reductions be constantly carried on. While this should be done by the designing engineers and by the operating forces in the factory, it is not their prime function. It has been found that a separate department, manned by men of technical training, with years of shop experience, has solved the problem. This department is called the cost-reduction department. Having in this department a group of selected men whose sole duty is to check into all quantity production for the purpose of saving pennies cannot be too strongly recommended. Being free from all routine work, they can concentrate on the study of the designs, processes, tool equipment, machine tools, floor arrangements, or any other factor entering into the cost Their recommendations for expenditures must always be accompanied by a statement of the savings. Usually, if the cost can be recovered by the savings in a year, the recommendations are adopted. At the end of the year, the accounting department sends to the works manager a report showing whether or not the savings have been made. The author could, if time permitted, tell of some almost unbelievable savings that have been accomplished by this department on such standard lines of product as washing-machine motors and fan motors. Their efforts are not usually directed to special products, because such designs are not repeated often enough to warrant the expense. The designing engineers and the regular works organization are expected to take care of the cost of these products.

Time-Study Departments

In all modern large plants some form of incentive wage-payment plan exists. Whether this be piece work, standard time, or any one of the many combinations, it is based upon a time study of some sort. It is obvious that this time study must be made by a disinterested party having the necessary shop experience to distinguish between false moves and necessary ones, to detect lost motion and improper handling, to decide whether the machine tools are suitable, the small-tool equipment ample and of the right sort, etc. The men assigned to this task form what is often called a time-study or rate department. The tendency is to set the time for performing each operation before the job is placed in work, especially when the operations are similar to previously performed ones. When they are radically different, a time study with a stop watch is usually made on the first production under day work.

Piece work is rapidly being superseded by other forms of incentive wage payments on account of its inflexibility. The official wage-payment system of the Westinghouse Company is known as "standard time." Under this system, every operation is timed so that it can be performed in that time by the average worker. If more time is taken, the operator gets the guaranteed day rate; if less, he obtains the allowed time at his hourly rate and a bonus. This system permits paying the going hourly rates, thus allowing costs to fluctuate with general market conditions.

As labor is one of the most important items in the cost, its conservation must be watched by the management. For this purpose, regular reports are prepared by the accounting department and distributed to interested departmental heads.

Purchasing

Material is the largest single item entering into the cost of the product. It is therefore essential that it be purchased at the lowest price to secure the desired quality and delivery on time. Even in a small concern, purchasing becomes a specialty. In a large concern, it becomes an organized specialty. Contact must be made with competitive suppliers, specifications for quality, etc., must be transmitted, terms of payment settled, delivery dates specified, etc. In large corporations doing business with a multitude of customers, reciprocal buying cannot be overlooked. The purchasing department under the direction of a purchasing agent performs these functions. How well this is done is judged by reports furnished to the executives in charge. One deviation

from standard practice has been found to be of value. While the purchasing department specifies the date of delivery on the purchase order, the following of this date to see that it is met or the changing of the date to meet a changed condition in the factory is the function of the scheduling or production department. In other words, the purchasing department makes the contracts, and another department deals direct with the supplier on delivery. This has worked very successfully, as quick action can be secured by the department most interested.

Scheduling

It is essential in a large plant that a systematic method be followed in furnishing delivery dates to customers, and then that these dates be followed to see that they are met. This is the function of the production, scheduling, or planning department. Quantity apparatus produced for stock is generally scheduled for a certain amount per month. Each day's production is recorded against this monthly bogey. Graphical charts, if simple, are an excellent means for following this type of production.

Special apparatus has to be handled as individual items. Each date has to be followed by some sort of a tickler file. For the management to judge whether or not this special apparatus is being delivered on time before complaints are received from the customer, a record is furnished showing the percentage of overdue orders in relation to the orders due during the month. A careful following of this record eliminates many embarrassing situations.

In addition to scheduling deliveries and constantly checking them, this department is responsible for ordering the material from the drawings and specifications and checking to see that it is delivered on time. The stores and stocks naturally come under the jurisdiction of this same department, likewise the packing and shipping.

Selection of Machine Tools and Small Tools, Factory Layouts

In a large manufacturing concern, the selection of the proper tools to perform the work in hand is most important, as large sums of money are involved in the purchase of the tools, and the time required to perform operations is definitely settled by the type of tools selected. The problem of reducing costs of certain designs without reducing wages is solved by reducing the labor required per piece. To accomplish this, labor-saving machines and small tools such as dies, jigs, and fixtures must be provided. When there is sufficient quantity, the purchase of such machine tools and small tools is easily justified. In many cases the desired machine tools do not exist on the market, and therefore have to be designed and built in the plant. A large tool room, therefore, becomes a necessary part of a large plant. The cost for operating such a tool room is quite an item, and as it is included in the overhead, the most efficient equipment and personnel should be provided.

After the necessary machine tools and equipment have been selected, the proper arrangement or grouping of these tools in the allotted space must be made. To reduce the cost of handling material, the accumulation of excess parts, and damage while in transit, conveyors of various kinds are used or else benches and machine tools are so grouped that the work can be passed along by the operators. Conveyors, particularly of the continuous-traveling overhead type, are fast gaining in favor, as they eliminate all tote pans, trucks, or other containers, and there is no need to pile the material in storeroom bins, only to be unpiled and removed later on. These "traveling storerooms" also furnish quickly an indication of too much or of too little stock. All factory layouts should be made in the form of tracings after the approvals of the departmental heads in charge of the operations have been obtained. From time to time, changes in the arrangement have to be made to secure the greatest economy. Such changes should always be incorporated on the tracing.

Inspection and Test

Nothing is so vital to maintain quality as inspection and testing. Without an adequately equipped and manned inspection department and test department, it would be practically impossible to operate any incentive wage-payment plan. It is obvious that those in charge of production are inclined to say that their product is good enough to ship. In a small plant, where the superintendent or foremen are familiar with the economies of the business and the consequence of sending poor work into the field, it is possible, and often practical, for such men to pass upon the quality. In a large company, the inspection and test departments are entirely independent from the manufacturing organization, the chief inspector reporting direct to the works manager. While this independence exists, it is essential that the inspectors work closely with the foremen and exercise good judgment in passing upon questions which may be matters of opinion, such as appearance and noise.

The amount of inspection in a plant is always subject to criticism as it is one of the large items entering into the overhead. It varies considerably with kind of apparatus manufactured, whether it is special, whether it is repetition production, etc. When the group system is used, it is greatly reduced, as inspection of the finished product only is required. A record of all rejects must be maintained and be given regular and careful attention. Too great a percentage merits penalization, particularly if repeated frequently by the same individual.

Plant Maintenance

In a large plant the maintenance of the buildings and building equipment, the grounds, roadways, pipe, and power lines is carried on in a systematic manner by a separately organized department. Nothing promotes a finer "esprit du corps" than to have all the buildings and equipment in first-class repair, the floors clean, windows washed, ceilings and walls painted, and an air of orderliness throughout the department. The toilets, wash rooms, and drinking fountains should be kept scrupulously clean. Plenty of spittoons should be provided, otherwise the cutting compound in machine tools may be contaminated with tobacco juice. Corners of stairways should be painted white, with the word "Don't" added in large black lettering.

Safety Work

In a well-managed plant, safety has a very vital place. From a cold-blooded standpoint, accidents are costly, and whether the company carries its own insurance or has it carried by a stock insurance company, it pays the bill. It is comparatively easy and is now quite general practice to guard the hazardous parts of machine tools. It is more difficult to get operators to follow instructions, such as wearing goggles, safety shoes, operating the safety devices, etc. Most accidents are due to this cause.

Physical examination now so prevalent in large plants has a beneficial effect in reducing accidents. By this means, employees are being assigned tasks suited to their physical condition and are fast learning the value of keeping the body in condition.

If some of the foolish laws on liability, such as the manufacturer being responsible for the loss of both eyes if he hires a one-eyed man, are modified, industry will readily employ more of the partially disabled, and by means of this physical examination, place them on suitable work.

Safety from fire is particularly well taken care of in a large plant, principally because of the rigid inspection and reasonable requests from the insurance companies for the installation of

safety appliances, such as sprinklers, fire walls and doors, fire extinguishers, etc. In safety work, prevention is far cheaper than the cure.

How to Retain the Advantages of the Small Plant

The advantages that a small plant possesses over a large plant are:

1 Ability to act quickly
2 Low cost on production of small quantity orders or special apparatus
3 Close relationship between employee and employer, tending toward a better understanding of mutual problems.

With the advantage of quantity production being in favor of the large plant, how can one at the same time obtain the aforementioned advantages of the small plant? This has been accomplished to a large extent in a number of concerns.

Ability to Act Quickly

In the Westinghouse company there always has been an adverse criticism on the quickness with which delivery could be made on special apparatus. It has been found necessary frequently to accept orders for special motors involving a change in windings or a different shaft length or mounting, on account of having quantity business of standard lines. It has been the practice to produce these so-called "specials," usually in small quantities, in the same department where the larger quantity apparatus was being produced. The result has been that the special apparatus is pushed aside by the workman because he cannot earn as much in producing it, by the foreman because of the difficulties in adjusting the equipment and selecting the operators, by the production clerks on account of the large amount of paper work involved, and so on up the line. After struggling for some years with the problem of producing these small quantity "specials" in as short a time as the small manufacturer, it was decided to organize a separate department for the production of orders of 10 units or less, regardless of whether those units were standard or special. If they were standard, parts were requisitioned from the department manufacturing the quantity, and only the special features or special assembly performed in the small-order department. All-around mechanics were employed. Universal types of tools, instead of special tools, were installed. In order to obtain the greatest effort on the part of the supervisory force to deliver the finished product on time, a bonus was offered, based on the overdue percentage at the end of the month. The result of the operation of a department of this nature has reduced delayed shipping dates to a negligible percentage. Instead of avoiding small orders, the company is now in a position to solicit this kind of business.

One other very important object was attained—namely, the ability to determine the actual cost of these special units—whereas before they were merged with the cost of the standard product to the detriment of the standard apparatus. This idea of separating the small-quantity special apparatus from the larger quantity apparatus has been followed for some time in the production of other lines, such as repair and spare parts. In the latter case, a separate factory has been established at Homewood, Pa., solely to produce non-current parts.

Low Cost on Small-Quantity Production

In a large organization, this is a difficult object to accomplish, due principally to the large overhead. It can be accomplished only by adopting the same practice as is followed in the small shop. In other words, the large plant must be departmentalized and equipped to carry out the same functions as a small plant. The aforementioned small-order department accomplishes this to a great extent, as experience proves that when the execution of an order drags out, the cost increases, and nearly always exceeds the estimate.

Contact Between Employee and Employer

It is impossible in a large plant for the president, or even the works manager, to know personally all or even a majority of the workers. That intimate personal contact between the "boss" and the man on the drill press can never be depended upon in a large organization to secure results. Something must take its place. Hence, an incentive plan for the worker permitting him to earn in proportion to his output. There are various schemes of paying in proportion to the output, ranging between day work and straight piece work. Only a few plants operate entirely on the day-work plan, and even in those plants the operators who fail to keep up to a standard are generally replaced.

An equal amount of effort on the part of the management has not been used in providing an incentive to the supervisory force. Of late, however, in many plants this has been recognized, and a supervisory bonus has been installed. This bonus is usually based upon a saving of expense or a saving in the direct labor in the product. It is obvious that some standard must be set up as a basis for this saving. While it has been argued that expense should be kept in proportion to the productive labor, a little reflection will disclose that it is an impossibility to obtain; therefore a bonus based on savings made in direct proportion to the productive labor is impossible to obtain when productive labor falls below normal, and is easy to obtain when productive labor goes above normal. The answer is to measure the expense on the basis of a curve rather than a straight line. This is logical. Why should the supervisory force be cut in half if productive labor is cut in half? One would not think of selling half of the machinery or tearing down half of the buildings to reduce the depreciation account by one-half. It is therefore logical to retain more than one-half of the supervisory force when productive labor drops to one-half. On the other hand, it is not necessary to increase the expense by one-half should productive labor increase one-half over normal. A bonus system has been devised based on a curve, and whether business is good or bad it is possible for the supervisory force to earn an extra amount if they save in expense over the allowed amount as shown by a curve for the different loads. This has had a tremendous effect in reducing costs, principally through overhead. Direct savings in cost can also be made if a foreman or other supervisor devises a new tool or a new grouping of tools which reduces the productive labor; he is entitled to a portion of the saving over a period of time. All of this means that an incentive system for both worker and supervisor acts as a substitute for the one-time personal contact between master and workman.

As it has just been said that the relationship between master and workman has been replaced by a bonus system to secure low cost, so it has been found necessary to replace the same contact with secured interest and pride of workmanship by other agencies. A man on the bench always appreciates an interest displayed by the man higher up in his personal affairs. This applies particularly to his private affairs, his health, the health of his family, the progress his children are making in school, etc. In a large plant, this interest on the part of the men higher up is lacking. It must be replaced, and, again, the organization does the replacing. The welfare department has been modified considerably since the paternalistic days following the war. The conclusion has been reached that welfare work should take care of the important issues of life, employment, sickness, accident, old age, and death, also insurance for the survivors. Some of these, such as accident compensation, industry has had to undertake,

due to legal requirements of the state in which the industry is located. Unemployment is still unsolved, although large industries are more apt to furnish all-year-around employment than are the smaller concerns.

The age limit has received considerable publicity, but in the actual operation of a large plant a man is rarely let go because of age. It is true that he may, due to physical infirmities, be unable to carry on his old work, but usually some lighter work is found, even though the pay may be reduced. Ultimately, he is retired or pensioned. In this respect the larger industry is more humane than the smaller one which does not have the necessary financial resources.

Employees' committees or factory committees composed of representatives of the employers and the employees to look after the welfare of the employees have also received much publicity. In a plant of 5000 or less employees, such committees are not necessary. Too frequently they are not in possession of all facts connected with shop problems, and they develop into fault-finding groups, become involved in wage controversies, and attempt to justify their existence to their fellow workmen by spectacular action rather than by real worth-while work. The functions they are supposed to perform can easily be handled by the foremen, with the understanding that the workman having a grievance can always appeal to a higher authority. In a plant of 10,000 or more employees, such a committee can perform a real function, if carefully selected, as the management is further separated from the men.

Summary

Large-plant management consists in controlling the personnel by arranging them in groups or departments, each to perform a specific duty under the supervision of a specialist. The combined efforts should result in a low-cost, high-quality product. The number of departments must be sufficient to cover all the activities involved in the production of the apparatus from the time an order is negotiated until the apparatus is shipped. The duties of each individual, group, or department should be defined clearly so as to prevent overlapping with resulting confusion. On an average one department head or group leader should supervise not more than ten men.

To be sure that each department performs its functions, a loading or bogey, or a budget, must be set, and thereafter regular reports in concise form of the actual accomplishment must be made as soon as possible after the accomplishment.

Cost keeping and cost reduction are of paramount importance in any size plant. To accomplish this, an incentive system for paying both worker and supervisor is an economic necessity. Expense control must be on a curve basis rather than a straight line.

A cost-reduction department, composed of a group of technical men with years of shop experience whose sole duty is to study designs, processes, tools, and layouts, to save pennies, is almost a necessity in a large manufacturing plant engaged in producing highly competitive products.

It is conceded that the large plant, with its highly organized departments functioning through written instructions, is slower to act than the small plant, with its small organization. This slowness can be partially counteracted by special departments within the larger organization, patterned after the small organization. Such departments should be self-contained in personnel and equipment, and as free from regular system as possible.

Low costs on special and small-quantity apparatus which are secured by the small manufacturer can be obtained by the large manufacturer by also organizing special self-contained departments, patterned after the small plant.

The personal contact between the management and the worker which is very close in the small plant is replaced in the large plant by a welfare department, which looks after the major issues in the life of the worker; namely, employment, sickness accident, old age, death, and insurance for survivors.

Discussion

W. J. Barrett.[2] A shoe-manufacturing company typifies a combination of the large operation through the small plant. This company has decided that a plant capable of manufacturing 300 dozen pairs of shoes per day is the economical size. This size of plant employs approximately 300 workers. In its expansion the company has maintained this size of plant. It now has six units located in the same community, and each unit is capable of turning out approximately 300 dozen pairs of shoes a day.

The company maintains that under this arrangement the cost of supervision is at a minimum, the overhead incidental to record keeping is lower, and operations are on a much more flexible basis.

Allan H. Mogensen.[3] It is interesting to note that the author mentions profits. Mr. Reynders says, "The sole object of any manufacturing plant is to make money by rendering a legitimate service." This question of profit control is one of extreme importance, whether it is a large concern or a small one. And, unfortunately, it is the large plant that usually knows its costs and practices profit engineering. Success in the long run will depend on the ability of the management to so budget their operations that profits are assured regardless of their sales volume. Those concerns that are weathering the present depression are the ones that have charted their course and are steering to it; in other words, they are living within their income.

Depreciation and obsolescence have been mentioned. The writer does not wish to get into a detailed discussion of the various forms of depreciation, but he does want to emphasize one thing. As long as we continue to consider depreciation as a liability, and enter it in the annual statement under that heading, we will find outselves in a difficult situation. Simple as it may seem, the basic rule set down by Dean Kimball, "No profits should be declared until all losses to capital through the revenue account have been replaced from revenue," is often ignored. The depreciation reserve should actually be a reserve, and should be represented by money in the bank or in some form of securities so that the cash will be available when needed. Until this is done, we can talk ourselves blue in the face about replacing worn-out equipment, modernizing the plant, and all the rest. If the money which should have been set aside to do this has been paid out in dividends, a time like the present, when we should be preparing for future production, catches us unprepared.

H. L. Freeman.[4] The paper is correct in its comprehensive outline of departments considered necessary for the management of present-day manufacturing plants, but when the author advocates patterning an organization after the army the analogy is too general.

Taking the branch of service most applicable, the Engineers, there is a combat regiment (849), general service regiment (1179), separate battalion (1071), and smaller special units for pontoon bridges, railway work, camouflage, etc. Instead of ten men, as

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[3] Assistant Editor, *Factory and Industrial Management*, New York, N. Y. Jun. A.S.M.E.

[4] Cost Engineer, Dixie Construction Company, Birmingham, Ala. Mem. A.S.M.E.

stressed so often in this paper under one man's personal supervision, there is a squad of eight men under the leadership of a corporal who is a working member.

The basic working unit consists of the four-squad operating section under an experienced sergeant. Then there is reached the beginning of the supervision stage, with a platoon of two or more section in command of a second lieutenant, on through a company batallion, to the regiment, the commander of which, a colonel, corresponds to the highest official in a plant employing 1000 men, which has been taken as the dividing line between small and large plants.

The engineer regiment can assign its proper units corresponding with the work required and therefore handle jobs of varying size within its present organization. Unlike the method proposed of having a separate department for special or small-order work, the regular force in a plant could be organized into squads to handle such emergencies and then revert to standard production.

HAROLD V. COES.[5] There is one factor in the management and administration of both large and small plants that is common to both, namely, obsolescence, which is one of the factors of depreciation. In many cases deterioration, the other factor of depreciation, is taken into account and charged into the cost of sales, but very rarely is this true of obsolescence.

There is an economic principle which states that the selling price tends to approach the cost of production, but it should be noted that in this case the economist did not mean cost of manufacture alone or cost of sales alone; the cost of sales included a reasonable profit. The cost of sales should include all the elements of cost. Now it is quite apparent from an analysis, in many cases, that the average return on net worth does not include a sufficient profit to provide an adequate return on the invested capital plus a surplus for future development of the business and to permit the necessary progress of the business by making funds available to care for obsolescence as and when it occurs.

In some instances obsolescence trends can be somewhat forecast. In most cases, however, the developments are so rapid invention follows invention, discovery follows on the heels of scientific discovery, that obsolescence occurs almost like a fire, instantaneously.

The consumer, therefore, is not paying in the price of the merchandise; he is purchasing an adequate amount which will permit the producer to make the progress that the consumers or the public expect him to make by providing surplus earnings over adequate return on invested capital that will permit obsolescence to be cared for, as and when it arises. In many cases the prices are so low that even the element of deterioration is not provided for or is inadequately provided for. Therefore management and consumers alike must learn that obsolescence is a factor to be reckoned with; that it has a definite bearing on profits and a definite bearing on wage earners, and also on continued and sustained prosperity.

[5] Consulting Management Engineer, Ford, Bacon & Davis, New York, N. Y. Mem. A.S.M.E.

AUTHOR'S CLOSURE

Mr. Barrett mentions that a shoe-manufacturing company has decided that a plant employing 300 workers and capable of manufacturing 300 dozen pairs of shoes per day is the economical size.

While this may be true for the shoe industry, the author does not see how so small a plant can afford to have a maintenance department for the upkeep of buildings and grounds and equipment, an accounting department, a purchasing department, and a shipping department. It is true that one of these departments may handle the functions of the other departments and thus reduce the personnel. On the other hand, if a larger unit, say of three or four of these plants, were possible, then the plant purchasing, accounting, shipping, etc., could function economically. At the same time, the factory could be divided into sections, so that each section could produce the 300 dozen pairs of shoes considered to be the economical unit.

Mr. Mogensen stresses the absolute need for setting aside a reserve for depreciation, and that this setting aside should be actual, not theoretical. In other words, the depreciation fund should be available at all times for the purchase of new, up-to-date equipment. The author agrees thoroughly with Mr. Mogensen in his views. Under no circumstances should the fund be used as a means for paying dividends, if such dividends are not available from other sources.

Mr. Freeman takes exception to a manufacturing organization being patterned after the army, as advocated in the paper. He states that instead of ten men, as advocated, eight is the maximum number in the army under the supervision of one man.

In the paper, the number of men under the supervision of one man is recommended to be ten or less, and therefore corresponds with Mr. Freeman's views.

Mr. Freeman also takes exception to the recommendation for a separate department for special or small-order work, and cites the plan used by the army of assigning units to the work required.

This can be done as long as the units consist of men only, each man having a rifle, a bayonet, a blanket, etc., but where heavy machine tools and special equipment are required, the conditions are entirely different. Groups for handling this equipment will have to be more or less permanent, and then we obtain the small-order department recommended.

The author agrees with Mr. Coes's remarks relative to obsolescence being a factor that must be reconciled by both management and consumer.

Progress in Materials Handling

Contributed by the Materials Handling Division

Executive Committee: G. E. Hagemann, *Chairman*, M. W. Potts, *Secretary*, R. H. McLain, F. D. Campbell, C. D. Bray, and E. D. Smith

IT IS IMPOSSIBLE to measure accurately the progress that has been made in materials handling during the past year. First, it is impossible to accumulate proper and sufficient data. Second, there is no real yardstick by which this progress can be measured. A questionnaire was broadly circulated in an effort to secure such information as would be helpful in bringing before this Division the nature and extent of the year's progress in materials handling. The replies received indicate that while there is a great deal of interest in the subject, there are yet many cases in industry where there seems to be little, if any, attention paid to it. The manufacturers of materials-handling equipment seem to be making real progress, and in several cases are doing special research work.

While most manufacturers of materials-handling equipment are conducting their own experiments, much is also being done with the cooperation and assistance of industry. For example, a certain industry will present a problem to a manufacturing company and will agree to work out as far as possible the materials-handling problem. In some cases this may present many mechanical and structural difficulties. The job is then built with the understanding that it will take some time to get the various problems solved. This has been particularly true with the automobile industry. Research work is being done to some extent, in colleges and in testing laboratories, along the lines of heat-resisting alloys for materials-handling apparatus passing through ovens at high temperatures, heat-resisting bearings, and the effect of combinations of water and heat. Lubrication problems, which are very important factors, are being given a great deal of attention and study by both the conveyor manufacturers and the lubricating companies.

Manufacturers of materials-handling equipment report increasing interest on the part of industry, stating that they are now frequently called into consultation when plans for changes or additions are in very early stages so that the scheme or plan under consideration may be developed with particular reference to proper materials handling. They report also that the increased output per unit of machinery has been a big factor in making proper handling methods a necessity. Another very important development seems to be the fact that the average manufacturer now has generally gotten away from the thought that his product could not be handled on chains or conveyors because it was "entirely different."

Clay Products

The tremendous increase in the cost of common labor compelled the manufacturers of clay products to seek mechanical replacement of common labor if the cost of their products was not to become prohibitive. While there has been no organized research work on the subject-matter, the clay-products manufacturers, their engineers, superintendents, and foreman have all engaged in the study of mechanical handling in an effort to reduce labor costs. Manufacturers of clayworking machinery and mechanical-handling engineers, of course, have aided in solving the various problems. Steam, gas, or electric locomotives and cars have replaced the mule carts that brought clay from its source to the plants, conveyers have replaced wheelbarrows in the plants and shipping yards, and tractors convey the finished product, deliver coal to the kilns, and remove ashes and waste material.

With every manufacturer and his working forces assisted by competent mechanical engineers engaged in research study, the clay-products industry has progressed more in the matter of materials handling during the present century than during several hundred years previously, and is now entitled to a very favorable rating as a mechanically equipped industry. These companies report also that savings in labor costs have been large and that the research work is continuing.

Railroads

Several of the roads surveyed have made elaborate studies of the problem of handling and transporting parts and material. Electric hoists on individual cranes and additional installations of traveling cranes have served to reduce handling of parts in process of manufacture or repair in the main shops. Motorized delivery systems have been installed to place material at the point of use and have served to eliminate the expensive and time-consuming method of handling parts by manual labor. In many shops electric platform trucks are now used to handle parts and materials that are loaded on skids.

Undoubtedly the development of the "spot" system of car and locomotive repairs has been the most important influence toward the increased utilization of materials-handling equipment. With this system, both locomotives and cars are moved through the shop from station to station. Only certain kinds of work are performed at a single station. The various parts are routed from the first station to the various repair departments, where they are overhauled and then moved to the proper station on the erecting floor. Lift platform trucks with skids have been found to be advantageous in connection with the spot system of locomotive repairs. In the case of car repairs under the spot system, crane trucks have been found very useful. In fact, several of the Class 1 railroads prefer crane trucks for car-repair work to overhead traveling or gantry cranes.

An interesting development in both car and locomotive repairs, especially coach repairs, has been the increased utilization of the overhead monorail. The railroads, being a transportation industry, are not organized to any important extent to carry on research and development work, and as a result have to depend almost entirely on the developments of materials-handling equipment made by the manufacturer. Railroad mechanical-department officers indicate, however, that they recognize the possibilities of substantial economy through the use of modern materials-handling methods.

Packing Industry

There were a number of developments in packing-house processing during the past year. Gasoline tractors have been designed which have the approval of the insurance companies for use under packing-house conditions. Formerly electric tractors were used, necessitating large rooms for recharging the batteries. The gasoline tractors have eliminated the need of these rooms. A scale used quite extensively in the weighing of coal from coal mines has been adapted to packing-house requirements, auto-

matically records the weights of products upon a tape, and does away with a scaler. A truck has been perfected that will handle conveniently a very much larger quantity of packing-house produce from departments or assembly rooms directly to the cars. This truck has supplanted a number of laborers and has speeded up the operation of loading. A saw has been perfected which will split the entire backbone of a beef carcass. This saw does the work very much more rapidly than was possible under the old method of hand splitting. Furthermore, skilled workmen are difficult to obtain for this operation. Insulated and refrigerated

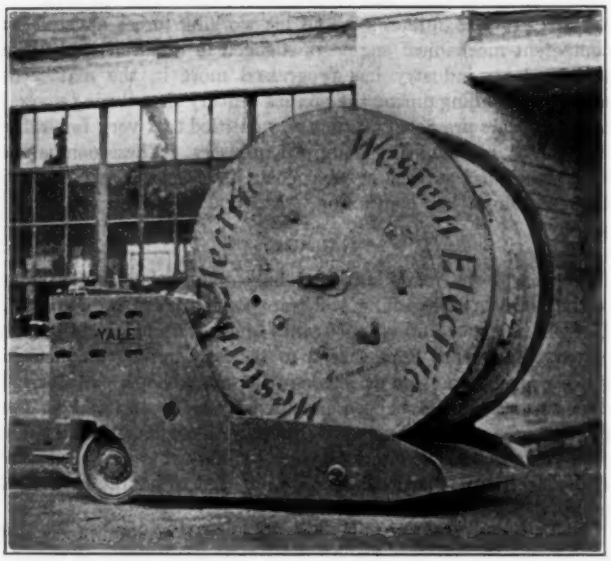


FIG. 1 NEW REEL-CARRYING TRUCK OF 10,000 LB. CAPACITY

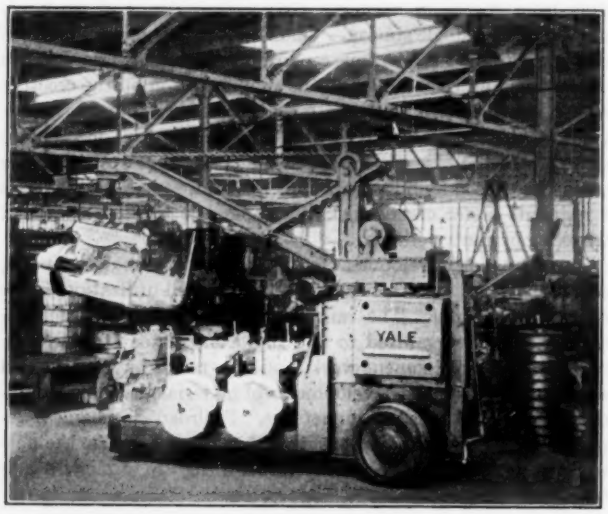


FIG. 2 6000-LB. LOW-PLATFORM, LOW-LIFT ELECTRIC INDUSTRIAL TRUCK WITH 1500-LB.-CAPACITY CRANE

meat trucks for delivery of meat products direct from packing houses to retail stores are finding increased use. These trucks are making deliveries to points at least 200 miles distant from the packing houses. Their use has eliminated several handlings of packing-house products required under the old system of delivery either by express or by peddler cars. Increasing interest is being manifested in railway refrigerator cars refrigerated by the silica gel system. If adopted, this method would eliminate the present need of icing stations along the route of shipment.

INDUSTRIAL TRUCKS

Fig. 1 shows a new 10,000-lb.-capacity reel-carrying truck. It is of the six-wheel type, having, in addition to the regular drive motor, a separate motor-driven unit which operates two

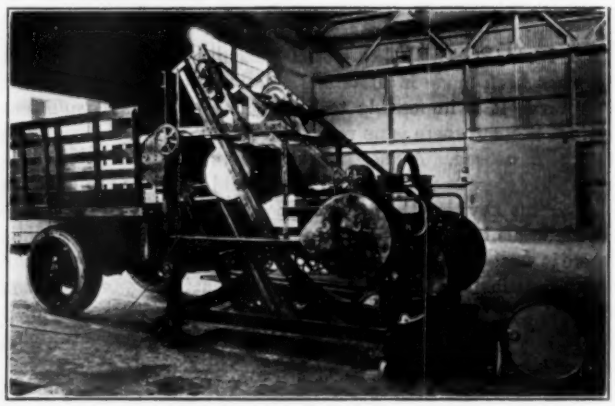


FIG. 3 PORTABLE BARREL AND DRUM LOADER FOR ELEVATING FILLED DRUMS FROM SHIPPING FLOOR TO TRUCKS OR CARS

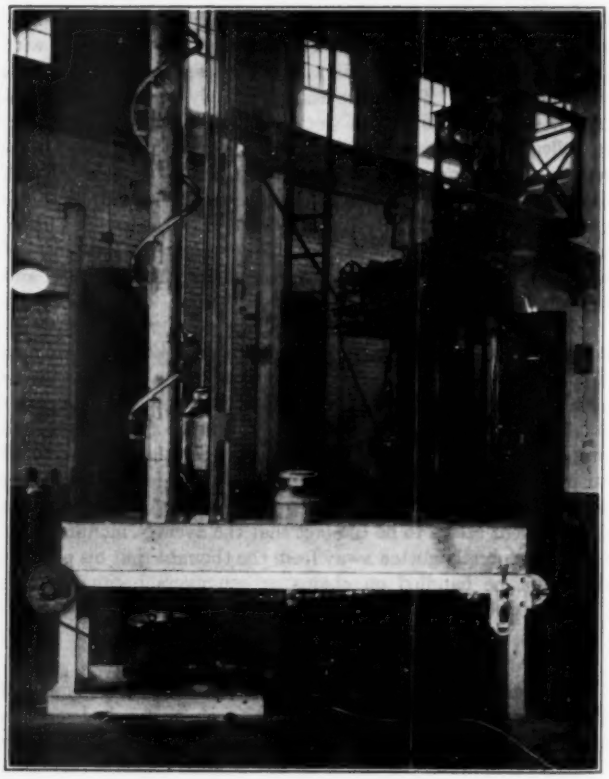


FIG. 4 DISCHARGE SECTION OF CAN DESCENDER

cables over a drum and idler sheaves. The truck approaches the cable reel and the pulling unit is set in reverse, allowing the cable to run out on each side. It is then fastened to a spindle, which is run through the reel, and the lever is thrown so that the pulling unit draws the reel toward the truck. The back end of the truck rests on the ground when the reel is not on the platform. The

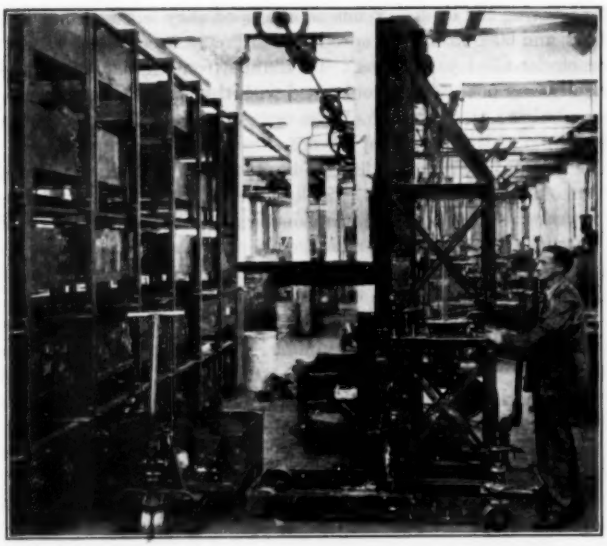


FIG. 5 ELECTRICALLY OPERATED STACKER FOR STORING BOX SKIDS

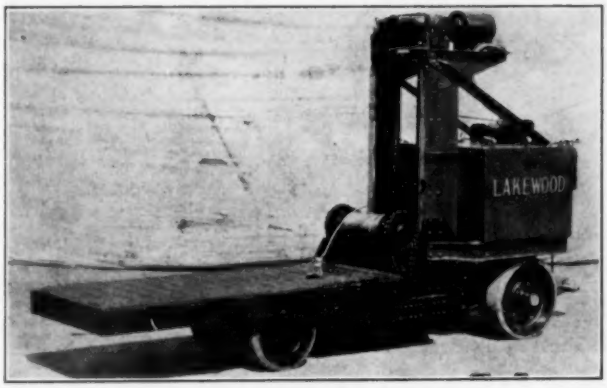


FIG. 6 TIER LIFT TRUCK WITH MOTOR-DRIVEN WINCH FOR LOADING HEAVY MATERIAL ON PLATFORM

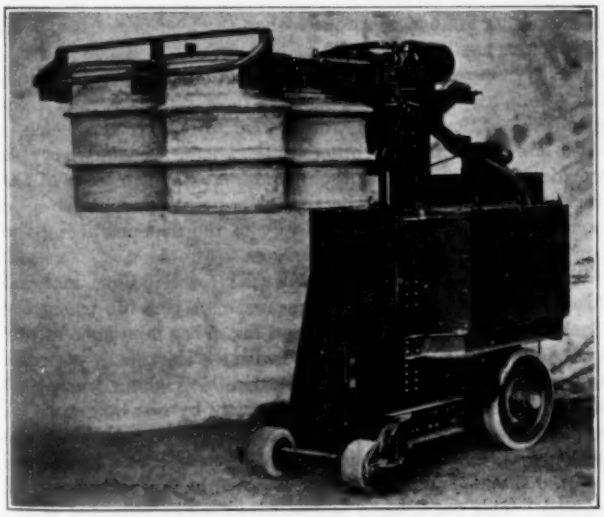


FIG. 7 SPECIAL TRUCK FOR HANDLING STEEL DRUMS



FIG. 8 LIGHT GANTRY CRANE FOR MACHINE-SHOP USE

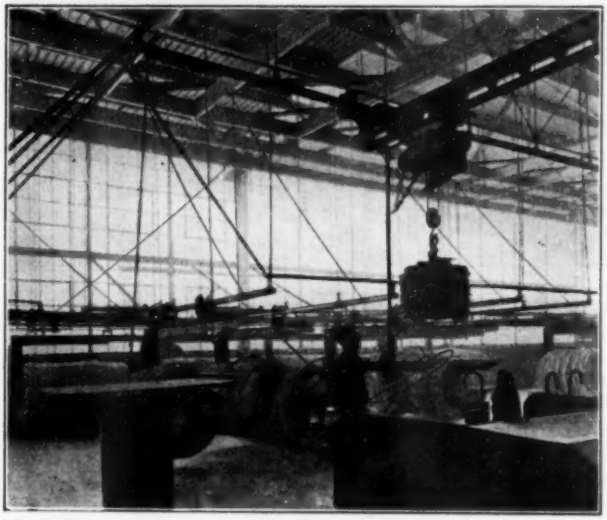


FIG. 9 HAIRPIN-HOOK FLIPPING DEVICE FOR USE IN WIRE MILLS

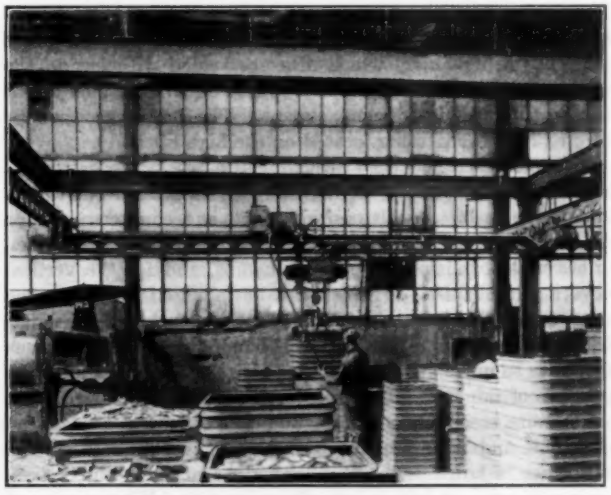


FIG. 10 POWER-OPERATED TRANSFER BRIDGE WHICH LOCKS AT BOTH ENDS WITH DISCHARGE POINTS AND PERMITS MOVING THE HOIST OFF EITHER END

action of the reel rolling past the center of the pivot in this platform causes the platform to rise into the position shown in the photograph. In this manner, very large and heavy cable reels are transported rapidly and with very little labor.

Fig. 2 shows a 6000-lb. low-platform, low-lift electric industrial truck upon which is mounted a 1500-lb.-capacity crane. This truck is primarily a low-lift skid-carrying truck having a platform lift of $4^1/_2$ in. The truck is shown with its own platform loaded, having been loaded by the crane, and an additional load on the crane hook. The articles shown being transported are marine engines, and it was not found necessary by the user to make use of skids in the transportation of this material.

Fig. 3 shows a portable barrel and drum loader for elevating filled drums from the shipping floor to trucks or cars.



FIG. 11 MULTI-RUNWAY TYPE OF OVERHEAD CRANE

Fig. 4 shows a milk-can or ice-cream-can descender that has been developed and is used as a power descender to convey filled or empty milk cans or ice-cream cans from upper to lower levels. In ice-cream plants very often the freezers are located on upper levels and it is necessary to lower the can of frozen cream from the freezer to the hardening rooms below. This type of unit fits into this need very completely.

The newly developed high-lift truck for the purpose of icing pullman dining cars has been recently placed in service at Buffalo. Using this truck, two men can ice 18 dining cars in $2^1/_2$ hours, whereas it formerly took 6 men 8 hours each to ice 15 cars. This truck has a high body which lifts up, loaded with ice, to the height of the dining car. It is only necessary for the men to put the ice into the icing compartment. The body can then be lowered from a controller located on the high-lift body.

This year there has been brought out a truck, the battery of which is mounted above the deck directly over the front wheels next to the dash. In this position it acts as a counterweight for the overhung loads for which this machine was designed, i.e., cranes with extensible topping-lift booms, and for the vertical elevating mechanism on which can be mounted shovels, crane arms, rams, stacking tables, and devices for stacking both cylindrical and rectangular packages. The mounting of these various devices is so made as to permit changing from one to another in a couple of minutes. This machine has the same wheel units, power units, steering mechanism, and control as were used on the older line, and these are therefore interchangeable between the two types of truck. The new trucks are made in three sizes, having 36-, 48-, and 60-in. wheelbase lengths. When equipped with a telescopic topping-lift boom, there are two power units mounted over the battery, one for raising the boom and the other for hoisting the hook. When so equipped they will handle 3600, 4800, and 6000 lb. at high speed over ordinary street pavements or on cinder-filled yard areas. To change from the shovel to the ram or any of the other tools used with this machine, it is necessary only to cast the rope off the equalizing bar and pull out the hinge pin at the bottom of the crosshead.

A similar elevating mechanism has also been brought out in the form of an attachment to the jack-lift truck which has been made for years. This attachment automatically locks to the frame of the truck, and then the jacks raise the attachment to the operating position in exactly the same way as the crane attachment which has been used with this truck for years.

Among the interesting jobs which these trucks have done this past year are the complete handling, mechanically, of freight on one of the Brooklyn, N. Y., piers. The use of hand trucks has been entirely eliminated on this pier, and the savings have been very substantial. At Barranquilla, Colombia, S. A., it has been found that, in spite of the fact that very cheap native labor is available, the two trucks which are used for handling the freight between railroad cars and storage and the shallow-draft river boats, have been paying for themselves every three months.

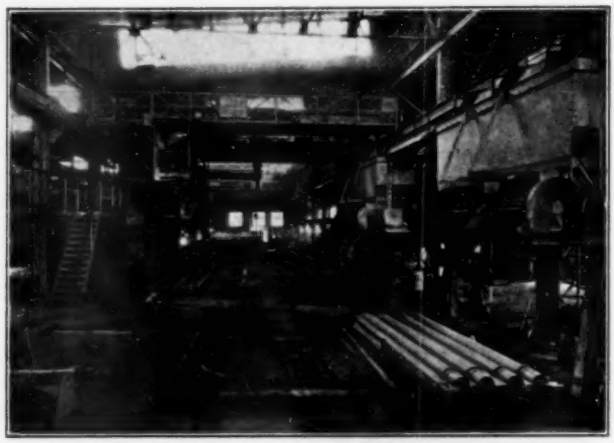


FIG. 12 FOUNDRY ARRANGEMENTS FOR CASTING IRON PIPE HORIZONTALLY

A new truck has been developed known as the foot-lift truck. This truck enables the operator to elevate the load by using the full weight of his body, rather than calling into play his back and stomach muscles, which are used when the load is elevated with the steering handle. The foot pedal is so designed that it automatically engages with the load-elevating means when depressed, and automatically disengages when it is returned to normal operating position. The room required to operate this truck is much less than with any other type, as it is necessary only to provide sufficient space for the operator to stand in front of the truck, whereas on the handle type it is necessary to have aisle room to bring the handle practically to the floor in raising the load.

Where standard box skids are used for handling material through machine processes by means of a jack-lift truck, the "Jack-Rack-Stack" system shown in Fig. 5 has been successfully used. For storage, they are racked with the electrically operated stacker shown in the illustration. Units weighing from 1000 to 2000 lb. are easily handled in this way by one operator. A saving of space is at once apparent, as the five tiers of skid boxes are handled from a single aisle.

Fig. 6 shows a new tier lift truck which has recently been developed. This truck has a motor-driven winch mounted at the rear of the elevating platform for loading dies and other heavy

material on the truck. This mechanism raises and lowers with the elevating platform.

Fig. 7 shows a recently designed machine for handling steel drums. The drums are loaded in box cars with this machine and are taken out of cars and stored two high in the warehouse. There has been a great saving in labor through the use of this particular machine, as the drums illustrated are filled with a paste used for making storage-battery plates and consequently are very heavy. Formerly one man was required to handle one

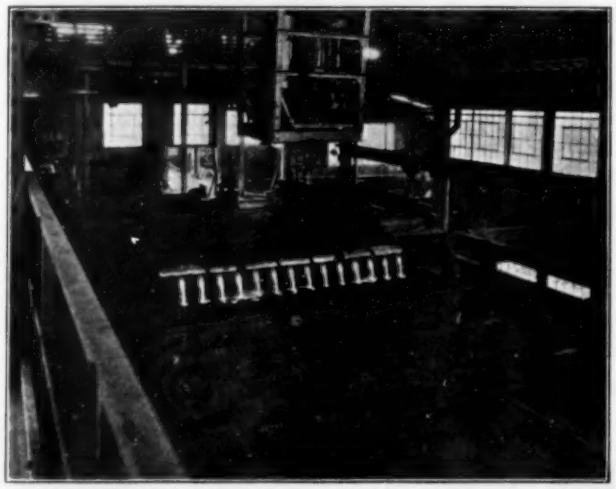


FIG. 13 MULTIPLE-LIPPED LADLE FOR POURING METAL IN HORIZONTAL PIPE MOLDS, AND CRANES FOR HANDLING FLASKS AFTER THEY ARE SHAKEN OUT



FIG. 14 MOTOR BRACKETS HANDLED ON VERTICAL SPINDLES BETWEEN MACHINING OPERATIONS

drum at a time, while the new machine is built to handle four drums at three times the speed of the man with the hand truck.

Fig. 8 shows what has been developed within the past year in the way of a gantry crane which can be moved with ease sufficient to warrant its use in a great many machine shops throughout the country. This crane has ball bearings on both the lower leg and also on the overhead half of the crane, and is so light and so designed that one-ton or two-ton loads can be picked up by the electric hoist at any point on the crane, and the entire crane moved by pushing on the load.

The "hairpin-hook flipping device" shown in Fig. 9 has been developed to supplant the practice, usual in wire mills, of moving material through the plant on floor-operated trucks, then removing each coil of wire from the truck and placing it on the reel before the wire is drawn. A flipper is installed on the end of a hairpin hook, and by properly applying this flipper, wire can be moved through the mill on a hairpin hook of this size in quantities of about 3000 lb. to the hook, and these hooks pushed in front of the wire-drawing benches, as shown in the figure, where the wire is flipped off the end of the hook without rehandling in the wire mill. The first installation of this kind was completed this last summer.

CRANES AND CONVEYORS

Fig. 10 shows a power-operated transfer bridge which is the result of several years of experiment in an effort to develop a transfer bridge which will lock at both ends with discharge points, and permit the hoist to move off either or both ends, as the case may be.

Fig. 11 illustrates the development of the multi-runway type of crane. The advantages of the three runways lies in the fact that by dividing the span of the crane in three sections, a much lighter crane can be furnished for a given load, with the result

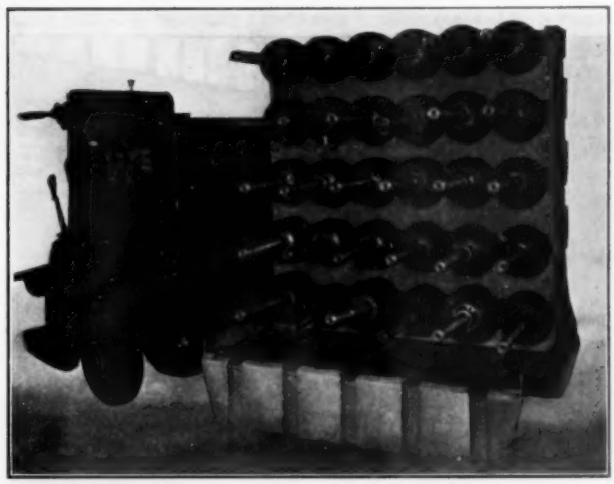


FIG. 15 INDUSTRIAL-TRUCK SKID WITH SPECIALLY DESIGNED RACK FOR HANDLING ASSEMBLED MOTOR ROTORS

that the weight of the crane is reduced to a minimum. This reduction is a decided advantage in connection with the use of hand propulsion, because there is less deadweight to handle. The lighter cranes also have a decided advantage from the standpoint of building construction, because, with the use of the three-runway or multi-runway type of crane, the weight of the crane itself usually does not exceed the load which it is designed to carry.

A rapid and extensive use of conveyor-type systems for electroplating and deposition of metals has been reported. Estimates made by the manufacturers of this equipment indicate in many cases that the labor is cut 20 to 25 per cent, and at the same time the material is transported from one point in the plant to another for the next operation. When such a system takes the place of the old still-tank plating, the floor space is only a fraction of what was previously required and there is an almost complete elimination of the very sloppy condition usually prevailing in plating rooms. Another significant development in the metal-working field is the handling method adopted by the manufacturers of tinplate and sheet steel, who are loading this material into freight cars on standard skids by means of storage-battery industrial trucks so that the recipient of these goods at the other end of the line can unload them from the same skids with the same type

of truck and effect a tremendous saving in the handling cost.

A manufacturer of automobiles has adapted the fork-type truck to select bodies of the correct color to fit the specification of the chassis on the assembly line. Previously bodies have been taken from the conveyor horizontally, mechanically tilted on the cowl end, then revolved, picked up by a truck, and finally stood on end. The new method has reduced storage 66 per cent and has saved an investment of $250,000 which had been appropriated for new storage warehouse.

Fig. 12 shows a somewhat unique development in foundry handling. In the foreground of the picture there are patterns for four cast-iron pipes in one flask. These pipes are cast horizontally instead of vertically as is the usual custom. Furthermore, they are cast in green sand and with green-sand cores. Fig. 13 shows a multiple-lipped ladle that is used for pouring these pipes, and also the cranes which handle the flasks after they are shaken out.

A railway car and foundry company reports the recent development and installation of labor-saving devices, the most outstanding one being a "wheel breaker" used in breaking old wheels which are to be charged into cupolas at the foundry. These wheel breakers have now been developed to the point where they



FIG. 16 TRUCK FOR HANDLING COMPLETE MOTOR PARTS FROM STORAGE TO ASSEMBLY LINE

are practically automatic and have reduced the number of men required for this work from five to one, or at the most, two. The company is planning the installation of a chain conveyor for delivering the broken wheel sections from the breaker to the cupola charging platform. This step is expected to result in a further elimination of three more men.

The materials-handling installation made at a motor-car company's plant in Detroit in connection with a new forge shop for crankshafts is of interest in that it is among the first attempts to put forge-shop production on a continuous basis. This development has been made possible largely through the medium of materials-handling equipment. The crankshaft forge shop is laid out for straight-line, continuous production, with no stock of parts at any operation. Travel of the metal from the original bar stock, through all processes, and finally into the railroad car for shipment, is handled by various conveyor systems. There are five forging units, three heat-treating furnaces, and two pickling machines. This equipment handles 7500 crankshafts a day. The time required to convert bar stock into crankshafts, delivered at the shipping platform, is only $4^1/_2$ hours. In all, 225 men are employed in this new forge shop. The success of this development, and the reduction in total costs of forging it has brought about, open the way for the extension of the idea to other forged parts produced in quantity.

At another plant in Toledo, Ohio, a materials-handling installa-

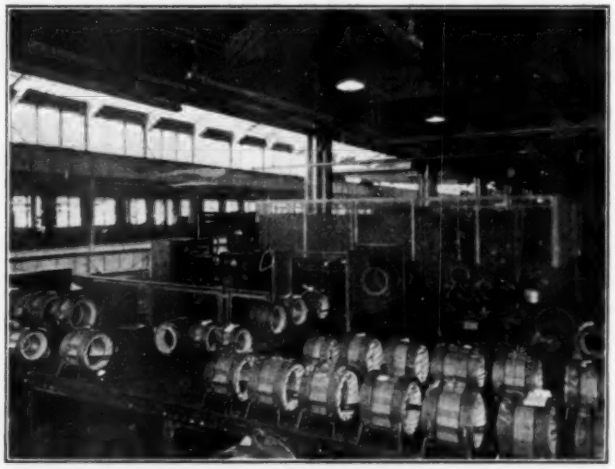


FIG. 17 POWER-DRIVEN CONVEYOR USED IN TESTING WOUND MOTOR STATORS



FIG. 18 NEW CRANE GRAPPLE WITH POWER OPENING AND CLOSING AND POWER SWIVEL FOR HANDLING LEAD-COVERED-CABLE REELS WITH AN OVERHEAD CRANE

tion was made which has revolutionized the manufacture of transmissions at the plant and reduced the floor space required for the output to about one-third of the former area.

Materials-handling developments at the East Pittsburgh plant of an electrical-equipment manufacturer have been along the

line of special equipment made to fit some certain job. This may or may not fit in with other standard materials-handling equipment, such as conveyors or industrial trucks. In attacking many of the problems in this plant, where so-called standard methods of materials handling cannot be applied, careful study usually shows a method of meeting the problem which results in lessened handling costs. Industrial electric trucks are being applied to an increasing extent, and with definite advantages on many lines of work. The flexibility of the truck is so great that it fits in excellently with the needs of such a plant, where the line of work varies from a small screw-machine part to a generator as big as a house. By using the trucks as a motive power for industrial trailers in addition to their own pay load, the company has effected considerable economies, and has also taken care of peak-production loads without the addition of extra truck equipment.

Motor brackets are handled on spindles between operations performed on automatic machines, as shown in Fig. 14. These occupy little floor space and may be adapted for quick handling by means of chain conveyors.

The adaptation of an industrial-truck skid with a specially designed rack for handling assembled motor rotors is shown in Fig. 15. This method keeps the rotors clean and free from damage and allows bulk handling from and to storage.

Fig. 16 shows a truck handling a number of complete motor parts which are secured from storage and conveyed to the assembly line. From the truck they are placed on a power conveyor where final assembly and test are made.

A power-driven conveyor used in the testing of wound motor stators is shown in Fig. 17.

A New Jersey manufacturer reports the use of a new crane grapple with power opening and closing and power swivel for handling lead-covered-cable reels with an overhead crane, shown in Fig. 18. This grapple eliminates the necessity of having a floor man to insert the plugs in the hub centers.

This company also reports the employment of all-water shipment of bare copper wire from Hastings, N. Y., to its plant at Kearny, at a marked saving over rail or truck shipment. This method involves the use of several hundred new box skids, seven flat cars in the yard, and a high-lift electric truck. With the exception of a manual inspection operation, the wire is not touched until it is unloaded at the insulating machine.

Skid Shipment

The Department of Commerce reports that this method of shipment has continued to grow, as well as the use of various types of containers for rail and water shipping. In some cases skid shipment has shown a very remarkable saving, one large paper company reporting a reduction in labor costs of 90 per cent.

E. D. Smith, *Chairman*,
Progress Report Committee of the Materials Handling Division.

MH-52-2

Fundamentals Which Should Be Observed in Design and Application of Tramrail Systems

By E. T. BENNINGTON,[1] WICKLIFFE, OHIO

The design of overhead conveyors and tramrail systems has gone through its period of expansion, change, and improvement with the results that this type of machinery is playing a very important part in a great many intensified and concentrated production schedules, and it is the expectation of those that are following the development of this business that it is destined to play a far more important part in the very near future.

There are many fundamental principles of design for overhead-conveying machinery that cannot be safely overlooked if a system is to be subjected to severe service. Even if it is not to be subjected to severe service, from the standpoint of safety and ease of handling, these principles should all be understood and observed. This paper contains only a few of the more important principles of design and application.



FIG. 1 RESULTS OF PEENING ACTION ON AN ORDINARY I-BEAM

NO SYSTEM using a rail of improper design can be operated successfully, for the backbone of any conveying system is the rail. There are several very satisfactory ways in which to provide a rail that will give proper service and will not be rendered useless by "peening," that enemy of every rail system, whether it operates overhead or on the ground. The ability to relieve peening is what determines the life of an overhead rail and a railroad rail; it is what determines the life of a floor made of steel plate such as is used in steel mills; and it is what determines the life of all overhead systems.

The results of the peening action can be described by reference to Fig. 1, which is an ordinary I-beam such as was used rather commonly in the past for overhead systems. The constant rolling of the wheels on this beam causes that part of the beam that comes in contact with the load-carrying wheels to peen or expand in all directions. When this expansion takes place, the metal thus moving must go in some direction, with the result that the flange must turn down as shown, because that part of the flange of the beam which is directly beneath the flange carrying the load-bearing wheel is not subjected to a similar expanding action, and consequently remains in its original position.

For many years it was thought that the reason for the flange turning down was because the rail had been overloaded. This theory has long been exploded. If an overload were to cause the flange of the beam to turn down, the flange of the beam would turn down the first few days that such a system was in service, but it has been learned in actual practice that the turning down of the flange does not occur for a considerable period after the system is installed and until it has been subjected to a great many passages of load-bearing wheels.

There are only four ways known to the author to provide a rail for an overhead system that will not be rendered useless in a short while by peening. Fig. 2 shows an ordinary I-beam provided with railroad rails attached to the lower flange of the beam, the wheels running on the rails and not on the beam. Fig. 3 shows what is known as a Pencoyd section that has a special wedge-shaped strip-steel member riveted with countersunk rivets to the lower flange of the beam. This design enables the rail to be installed with curves of somewhat shorter radii than that shown in Fig. 2. If wedges of the proper size for the load to be carried are used, this will make an excellent system, and can be subjected to the very hardest kind of service.

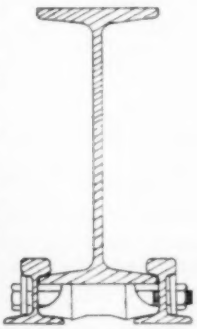


FIG. 2 RUNNING RAILS ATTACHED TO LOWER FLANGE OF I-BEAM



FIG. 3 SPECIAL WEDGE SHAPED PIECES OF STEEL RIVETED TO LOWER FLANGE OF I-BEAM

Fig. 4 illustrates the new type of I-beam that has been developed by several steel mills, and that has flat flanges to which strips of steel can be welded or riveted which will make a good overhead carrier. Fig. 5 illustrates the type of rail used by one manufacturer specializing in the construction of tramrail systems. This is rolled in one piece, and made of high-carbon steel. It provides a flange that will not be distorted by peening, although peening still takes place the same as it will in all of the shapes and suggestions offered in the previous figures. In all four types illustrated the metal which is peened or expanded works off the rolling surface in the form of the flange without distorting the shape and without rendering it unfit for continued use.



FIG. 4 I-BEAM WITH FLAT FLANGES

THE SWITCHES

There are two types of tramrail switches which are used, the

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Contributed by the Materials Handling Division for presentation at the A.S.M.E. Akron Meeting, Akron, Ohio, October 21 to 23, 1929. All papers are subject to revision.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

tongue-type switch and the transfer switch. The tongue-type switch is the cheapest to build, and is satisfactory only when used in connection with tramrail systems employing carriers that are hand-pushed along the rail. This type of switch should not be used with electrically propelled carriers because of the impact caused on entering the switch. The design is such that a bad rail connection cannot be avoided at the hinge of the switch, and the direction of the load is changed suddenly at the same point. For this reason a severe impact is thrown into the system as well as the carrier if the electrically propelled carrier is traveling at the usual speed for such devices.

The transfer-type switch shown in Figs. 6 and 7 provides a smooth path through which the carrier can operate. The rail over which the carrier passes will bend to a very short radius, nevertheless there is no obstruction or wide gap that will cause impact, and it is for this reason that nothing but the transfer-type switch should be used when power-driven carriers are selected.

On systems using hand-propelled carriers which are to be subjected to hard service, the transfer switch will be found to reduce maintenance costs and improve operating conditions. The transfer switch is often justifiable when used in connection with applications of this sort.

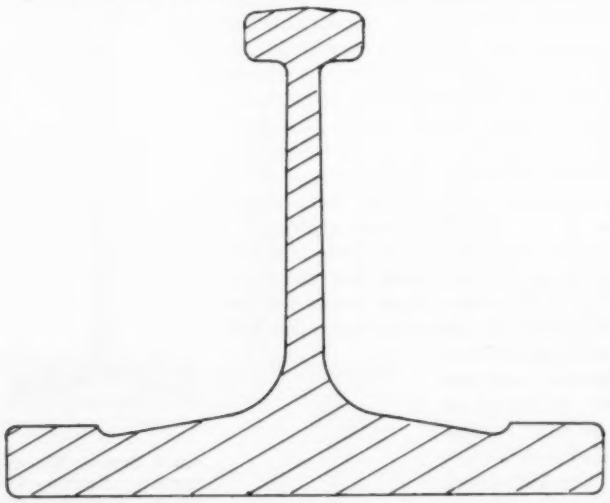


FIG. 5 RAIL ROLLED IN ONE PIECE

HAND-PUSHED CARRIERS

Without question so-called anti-friction bearings of some kind should be used on all hand-propelled carriers. It has been noticed that all manufacturers of these carriers are coming to the use of ball bearings although some types of roller bearings will provide good operating conditions. As users of tramrail systems are requiring more and more in the way of flexibility for the systems, some wanting rail bent as short as 18 in. radius, it is necessary to have the carriers designed with a long wheelbase, and with wheels that swivel independently on each end of a long load bar. (See Fig. 8.) The long wheelbase enables the carrier to negotiate curves with less tendency to bind and jerk, and the swivel ends permit natural movement of the flanges of the wheel and prevent digging into the rail on short curves, which always occurs if the four wheels on the carrier are locked rigidly together.

ELECTRICALLY PROPELLED CARRIERS

An electrically operated carrier that is not properly designed and constructed will not only be a source of high mechanical repair expense, but is likely to represent a real hazard to the operator and others. (See Fig. 9.) There are some fundamentals of design that should be embodied in every electrically propelled carrier that is put in service. Such a carrier should have the operator's cab separately supported from that part of the carrier that carries the load. The practice sometimes followed of carrying the operator's cab from the main body of the hoist is to be severely condemned.

It is not uncommon for an operator to try to pick up a load that is either attached to the floor or that is held in place by sticking or shifting of piles with the result that the lifting effort is many times that for which the carrier is designed, and something gives way. If it is a king pin, a wheel pin, load bar, or hoist, the operator suspended from the load-carrying member will surely drop with that member, whereas if he is separately supported on the rail, the rail itself must break before he can be injured. There is little likelihood of his ever reaching the ground as the rail is always the strongest member on any monorail system.

The increasing demand for high speeds and carriers that will negotiate curved rails of very short radius has brought about the introduction of spring suspension and swivel ends with two wheels only in each end. Carriers operating at speeds of 600 f.p.m. or greater could not possibly withstand hard service unless the weight were sprung. It can easily be imagined what would happen to a railroad roadbed if the freight cars were built without springs for the load; the cars and roadbed would be pounded to pieces in a very short while, and the same thing would happen to an overhead-conveyor system regardless of the kind of material from which it is constructed. The demand for high speeds has made the use of springs imperative, and they were unheard of eight years ago.

Swivel heads are of equal importance when curves of short radius are encountered in the rail. If all four load-carrying wheels were locked together, the flanges on the wheels would cut away the rail on the inside of the curves even though the wheels were located very close together.

Another very important fundamental design that should be incorporated in every electrically propelled carrier is the feature of long wheelbase, as the greatest practical and possible distance between the wheels that carry the load. Strange as it may seem, the long wheelbase has a remarkable influence in preventing a load suspended from the hoist from swinging out of control when negotiating a curve at a lively speed. This feature of long wheelbase is just as important to the electrically propelled carrier as it is to those that are pushed by hand.

FUNDAMENTALS OF APPLICATION

Every successful installation of material-handling machinery is successful because it does one of two things. It either eliminates rehandling operations or it permits the handling of more material each trip. There are many who have a great deal of faith in what can be accomplished through the use of these two fundamental principles as applied to overhead conveying, but there is also the large majority of engineers who have not yet come to realize the real advantages in store for them through proper use of these principles of overhead-conveying machinery.

The savings and advantages do not lie alone in reducing the cost of the payroll for the men actually engaged in the moving of materials. The application of these principles has usually a far-reaching effect. It has been known to affect the operating costs in every department in some of the largest plants in the country.

As an example of elementary rehandling operations Fig. 10 shows the handling of coils of wire in a large steel mill. There are 3300 lb. of wire on the hook made up of 11 bundles weighing 300 lb. each. Before the installation of the tramrail system shown, there were 20 men employed in the handling of this wire rod as it came off the mill. It was rehandled many times before it entered the manufacturing department or was placed on cars.

As it came off the mill it was put on trucks, one bundle at a time by hand, then the truck was either pushed to the storage yard or to the cars for shipment as wire rod. If it was to be

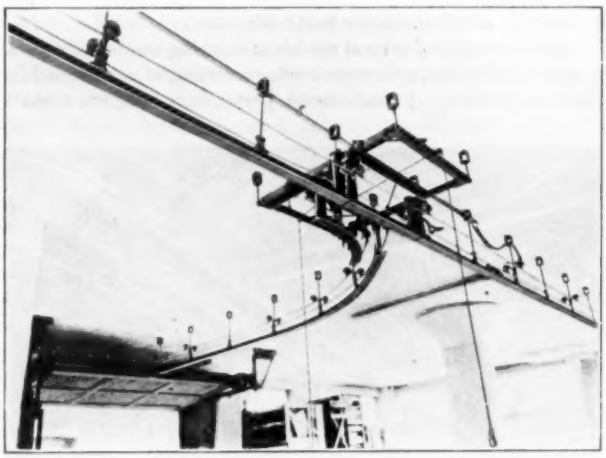


FIG. 6 THE TRANSFER TYPE SWITCH PROVIDES A SMOOTH PATH FOR THE CARRIER

loaded on the cars, the truck was pushed to the side of the car, and each bundle was hoisted by hand to the inside of the car, and after reaching the inside of the car it was again moved by other men to its final position inside the car for shipment.

By the introduction of a properly planned tramrail system, the bundles are dropped in a long row from the cooling conveyor, standing up about as they are shown resting on top of the car in the illustration. The rail being suspended over this row, the operator has but to cause the hairpin hook to be lowered to the proper elevation, and then move the carrier forward until the hook is inserted its full depth into the coils. Then the hook is raised until the load is clear of the ground, and the carrier is moved over the car, where the load is deposited in its proper place.

A conception of the relative capacity of hand labor aided by trucks and the hairpin hook unit on the tramrail system can be obtained by considering that the capacity of 20 men and a few trucks was 200 tons loaded into cars per day, whereas one unit is capable of loading 900 tons per day if the capacity of the wire mill were such that this amount of material could be produced and to enable the operator with the carrier to be employed constantly.

This is a good example of what a properly planned tramrail system will do, but it is not by any means an exceptional example. There are hundreds of installations made about the country each year which have effected equal results in proportion to the cost. Some of the indirect savings resulting from an application of this kind are elimination of tangled bundles, as they are not handled so often, and they arrive in the manufacturing department in very good shape, thus reducing the non-productive time on the machines while the bundles are being untangled.

When hand labor was used, it was not uncommon for the mill

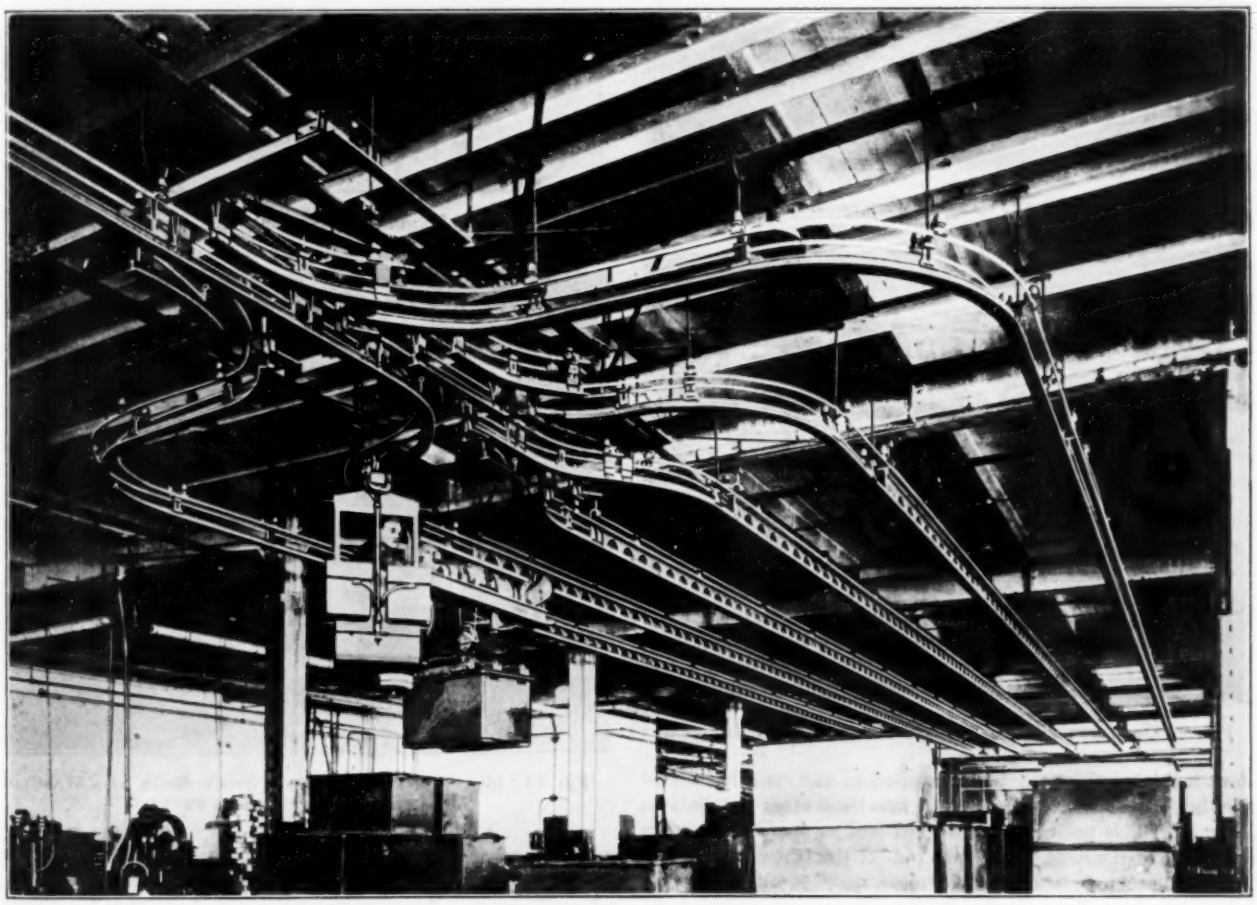


FIG. 7 SHORT-RADIUS BENDS ARE OFTEN NECESSARY

to run ahead of the handling crew, with the result that the mill had to be stopped occasionally until the congestion was removed. This congestion has never occurred since the tramrail system was installed.

It would undoubtedly be interesting to discuss similar installations involving this principle as applied to various other industries but space will not permit going into these other installations in detail. This principle has worked just as successfully when applied to textile mills, paper mills, rubber-tire factories, bolt and nut manufacturers, fence manufacturers, metal furniture, electric-refrigerator factories, potteries, machine shops, and many others.

Fig. 11 shows how more material may be handled each trip. The stock room of an electric washing-machine manufacturer is shown. Before installing the tramrail system, the usual type of stock room was used consisting of long rows of bins in which the smaller parts were kept, and four-wheeled trucks cluttered all over the place in which the larger parts were kept.

In the assembly of several models of washing machines, several thousand different parts were used, consisting of screw-machine products, castings, pressed-metal parts, bars, angles, motors, switches, etc. The material was withdrawn from this stock in the usual type of tote box of a size that would hold about 50 lb. of small screws. As an operator ran out of material his supply was replenished in containers of this size or in bundles of angles,

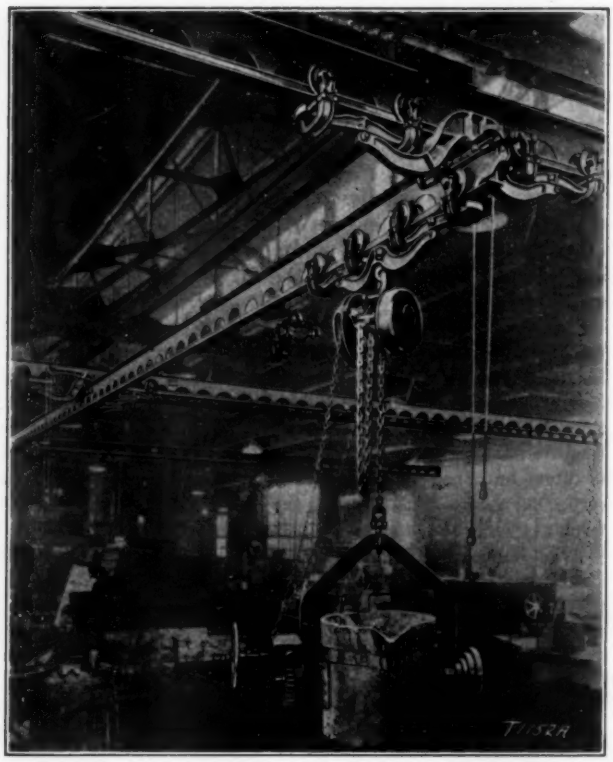


FIG. 8 HAND-PUSHED CARRIER WITH LONG WHEELBASE

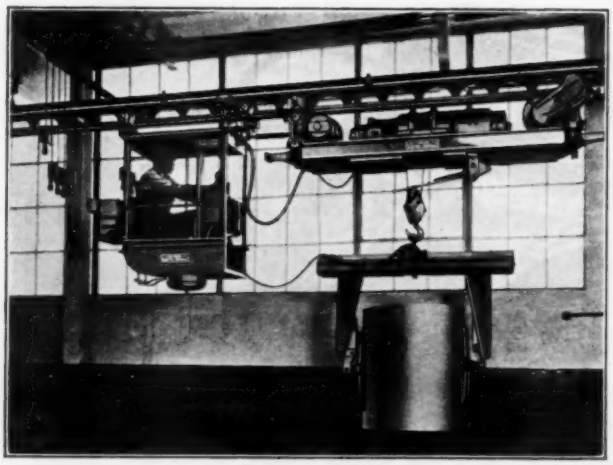


FIG. 9 OPERATOR'S CAB SUPPORTED SEPARATELY FROM CARRIER

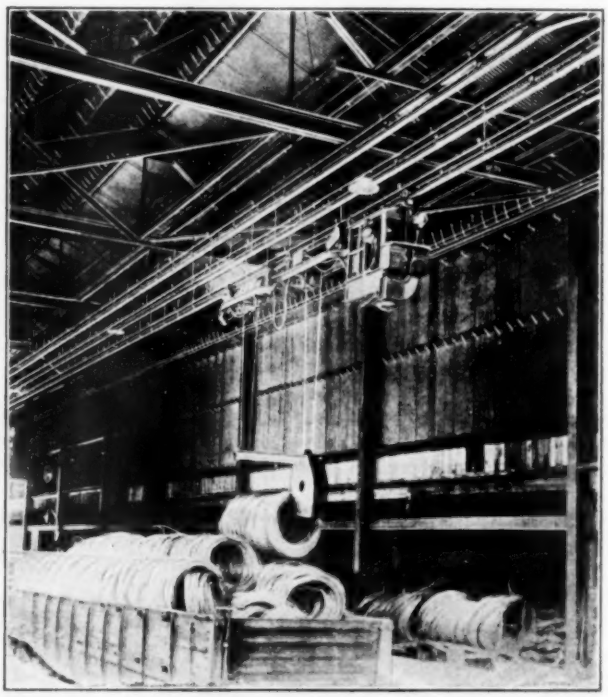


FIG. 10 HANDLING WIRE COILS IN A LARGE MILL

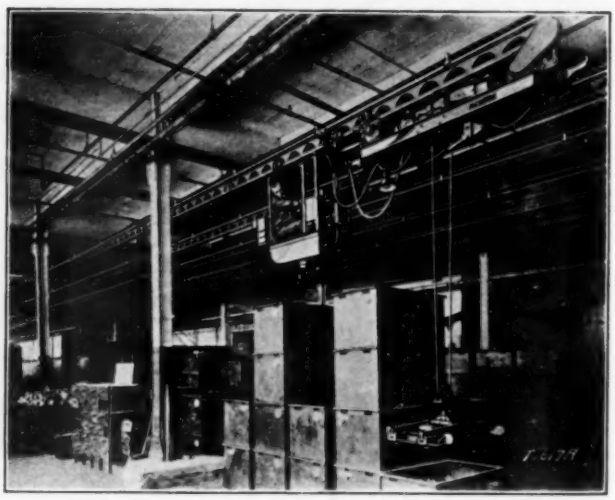


FIG. 11 MATERIAL HANDLING IN A STOCK ROOM OF A WASHING MACHINE MANUFACTURING PLANT

rod, etc., depending upon the nature of the material being used at that time.

If the stock of only one small part should unexpectedly become depleted, no more machines of this model could be assembled until the supply was replenished. This manufacturer took the first step toward successful handling of his material when he established a definite stock run for each model of machine. He then purchased 300 steel containers, all of which had the same dimensions on the base and varied only in height. The cubical capacity of these containers was fixed so that there was a size to hold the exact quantity of any part required to complete the previously established stock order.

Assume that the established stock order of model X machines was 500. The purchasing department would purchase the various parts required in the quantity that provided the lowest price.

When these parts were received, 500 of them would be put into one container if only one piece was used on each machine. If ten pieces were used on each machine, 5000 would be placed in the proper-size container as they were received and checked in the receiving department.

Where parts were too large to get into one container in quantities of 500 these were placed in two containers or five containers, and those containers plainly marked $^1/_2$ stock order or $^1/_5$ stock order to conform to the quantity they held. There were also a few cases where several kinds of very small parts were grouped into one container. These were parts that did not require any manufacturing operations before assembly. They were placed in this container in such a way that they did not become mixed up but were separated from each other by partitions.

Those parts that did not require manufacturing or finishing were moved to the machines as the schedule of each department permitted, and after the completion of the machine operation they would be moved back into stock to await assembly. This relieved floor congestion in the manufacturing department.

Aside from the saving effected in handling large units at one trip, and eliminating rehandling, the inventory system, cost system, and record of material lost in manufacturing operations could be more accurately accounted for. Since a tramrail system was employed to handle these containers with a special automatic grab that enabled the operator to attach or detach the load from the cab without the aid of any one on the ground, these containers were piled four or five high, and aisle space was entirely eliminated. The capacity of the stock room was increased about 400 per cent, and the cost of a new building which would otherwise have been necessary under the old scheme of things was saved entirely.

It has been the author's observation that fully 80 per cent of the manufacturing plants that are not accustomed to the use of material-handling machinery, and particularly overhead machinery in large ways, do not begin to realize the savings that are effected through the application of these two principles of handling materials. It is true that it is difficult for any engineer to determine definitely just how great these savings will be. It is one of those things for which no definite plans will probably ever be developed for calculating purposes because of the various conditions encountered in the plants, but it is not difficult to go back after these principles have been adopted by some manufacturer, and compare the cost under the new scheme of things with that existing before application of these principles.

MH-52-3

Incentive Payment Plans for Material Handling

By C. A. FIKE,[1] EAST PITTSBURGH, PA.

In this paper the author describes the methods used in installing incentive payment plans on two different phases of material-handling activities at the East Pittsburgh plant of the Westinghouse Electric & Manufacturing Company. The first phase is that of industrial electric trucking, the other is a material-supply group in the motor-manufacturing department. Detailed formulas used in the installation are included.

MATERIAL handling presents a fertile field for wage incentives. No appeal is stronger than that to the pocketbook, especially when made to workmen on this type of work where there may be small opportunity to create interest or enthusiasm due to its monotonous nature. Such work usually appeals to a certain type of workmen, but unfortunately this type is not often a production man, and unless interest is aroused in some manner, the entire production-line efficiency is affected. However, if an incentive is placed on the work, and the worker realizes that output affects the sum of money he receives in his pay envelope, the results are often astonishing; output per man increases, labor turnover is lessened, and it is no longer difficult to keep men on the monotonous jobs. In jobs where heavy physical effort with slight mental energy is the requirement, the results are the same.

The primary cause for an incentive wage-system installation is to increase manufacturing efficiency by supplying a reason to the worker for taking full advantage of all facilities provided, as well as a stimulant for increased personal efficiency, both through mental and physical effort. The worker provided with such an incentive will make effort to avoid delays, rather than invite them as giving an opportunity for a rest, and where some delays are unavoidable, will exercise his ingenuity to minimize them. The increase in earnings brought about in such manner attracts and holds a better type of worker.

In placing an incentive on material-handling work, considerable preliminary work must be done, especially if it is on work which is entirely new to such procedure. If it is the latter type, effort should be made to pick out that part which will most quickly and clearly show results. In other words, establish incentives on the easier jobs first, and those that are harder will not be so difficult when installation is finally started on them. Before any time studies are taken, the workers should understand what is to be done, and as far as possible how it is to be done. As a rule, if the "stage is set," in this way the worker becomes an active and willing participant in the installation, and the work is facilitated to that extent.

Securing a Measurement

In setting an incentive on material-handling work, probably the hardest thing to determine is the unit of measurement. In ordinary production work, the piece or part is usually the yardstick; such cannot always be the case on material handling. Take for example, the loading of miscellaneous material on railway cars for shipment. The pieces are unlike in size and weight, and to place separate values on each one would be impractical as the cost of clerical work would outweigh the labor savings. However, in such a case, the car weight unit can be used; cars are weighed before shipment, so the unit is available without any extra work or expense. From this it will be seen that each material-handling job must be considered as a separate problem, each with its own solution, but all based on a common principle. The unit of measurement must be understood easily, and require no great amount of clerical work or supervision in its application. Careful checking and a thorough understanding of the job under consideration will ordinarily show some logical unit which will meet these requirements.

Method of Payment

Material-handling work is usually performed by several workmen, each dependent upon the other in order to secure cooperation, coordination, and efficiency. For this reason such work can be placed advantageously on a group incentive. There are variations of this where the work may be included with a production group of men, or where the time value for material handling may be included with the production operation. If the latter case, and the production part of the work is also on a group incentive, a material handler may be included as one of that group. For example, a group of workers are dependent upon a trucker for material supply; by placing the trucker within the group, he realizes that his earnings are dependent upon keeping the group fully supplied with material at all times, and at the same time the group will aid the trucker to do his work properly, knowing that their earnings can be made higher or lower in proportion to the trucker's efforts.

The installation and operation of groups in connection with various kinds of industrial work has been pretty well covered in various papers and magazine articles, but a word of explanation may not be amiss at this time. A number of workers are placed in a group; earnings are pooled and distributed on a pay-period basis of the total hours worked by each individual in the group, times his individual rate. A simple example will illustrate this. Four men have made a total of 400 hours in a group during a pay period; A worked 100 hours, B worked 80 hours, C worked 50 hours, and D worked 170 hours. Earnings would then be distributed as follows:

$$A = \frac{100 \times 400 \times \text{Rate}}{(100 + 80 + 50 + 170)}.$$

$$B = \frac{80 \times 400 \times \text{Rate}}{(100 + 80 + 50 + 170)}, \text{etc.}$$

Provision is made for various grades of work within the group by a difference in the individual rates of the workmen, supervision within the group is taken care of by extra compensation, but percentage of gain or bonus earnings are divided entirely in accordance with work performed within the group.

Examples of Actual Installation

Two varying phases of material-handling work will be used as an illustration of what has been actually accomplished in the

[1] Superintendent of Plant Transportation, Westinghouse Electric & Manufacturing Co.

Contributed by the Materials Handling Division for presentation at the A.S.M.E. Akron Meeting, Akron, Ohio, Oct. 21 to 23, 1929. All papers are subject to revision.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

way of establishing incentives. First, that of an industrial-trucking scheme covering the entire East Pittsburgh plant of the Westinghouse Electric & Manufacturing Company, and second, the method of payment for a group handling raw and finished material in a motor-manufacturing department.

Actual figures are given, not with the idea that they can be applied to similar work in other plants, but in this way the work can be explained and understood more easily.

Industrial Trucking

Industrial trucking for the plant is centralized in one department whose responsibility is to furnish prompt and adequate trucking service on call from any production section. Trucks are controlled and service is given on a "taxicab system." Stations are established at four places in the plant in charge of a dispatcher who receives by phone or by direct word all requests for service, and dispatches trucks in accordance with such needs. Each station comprises a group, with the dispatcher as group leader. Payment is based on "loads," record of which is taken from truck requisitions made out by the section securing service. Since these same requisitions are the basis of billings for service rendered, there is slight chance of any requisition being received except those for actual service rendered.

The work performed by the time-study department preliminary to actual installation of time values involves a large amount of checking and study. The time-study write-up of this work follows in Appendix 1. Since it does not give the method of taking the time studies a word of explanation may be helpful.

Studies were taken covering all types of loading in the district covered by the group. These studies covered loading, unloading, running time, and delays. From a large number of studies, time values were selected which covered an average load under average conditions; such figures were secured for both types of trucks (platform and lift) in use as well as for trailers. These were then checked against actual figures, and approved for use as shown in the write-up.

The write-up in Appendix 2 is self-explanatory, and is a good example of similar plans in effect throughout the plant.

Conclusion

From the foregoing it will be seen that no general rule can apply to this type of work; each is a separate problem. Common sense and a full knowledge of the work involved are just as necessary as time-study engineering skill. The group plan is peculiarly fitted for such work, and averages are used to a large extent in determining values.

The number of workers required to perform this work after measurement and incentives have been established has been greatly decreased, in some cases more than 50 per cent, and when it is realized that material handling sometimes composes as much as 80 per cent of the labor content of a manufactured article, it can be readily seen that the time, training, and effort placed into such work pay large dividends both to the company and to the worker.

Appendix 1—Incentive Wage-Payment Plan for Industrial Trucks Working From North Yard Dispatch Station

Effective August 1, 1928, all trucks operating from this station, including the dispatcher and dispatcher's clerk, will be conducted on standard time-wage incentive plan by a group of twelve (12) men.

This station is in charge of the movement of material from all sections in Z building, I building, storerooms Nos. 8, 14 15, 16, 17, 18, 19, 20, 21, I-gate, and AB shipments transferred from industrial railroad to industrial truck for delivery to section.

A requisition for industrial truck service (Form No. 14284) must be given for each delivery of material, the definition of a "delivery" being any amount of material up to the maximum of one truck load which goes to one specified shop section.

The requisition will cover the delivery of the material to any point in that section, except in cases where one section is on more than one floor, making it necessary to use the elevator, the trucker should then be directed to the floor where the material is needed. In case the material has been misdirected, another requisition, properly signed, must be given the trucker before he will move it to another section. This trip will be charged against the original shipper who will be notified of same by the dispatcher.

It is imperative that material be ready with all necessary paper work attached, when the trucker reports to make delivery. In case the material is not ready, the trucker may be given a substitute load, but if no substitute load is available the trucker should be given a "No-Load" slip, and sent back to the station. An endeavor should be made, in so far as production requirements permit, to report full-load quantities destined for one section or another nearby.

For delivery of waste every Thursday, the trucker shall be given ten (10) slips, and for delivery of pay boxes, five (5) slips.

The group shall be allowed 0.336 hour for every delivery made by flat trucks and 0.252 hour for every delivery made by lift trucks.

The formula to be used in calculating the group's earnings will be $ET - TT \times F + TT = TA$

Where, ET = established time
TT = time taken
F = 0.25
TA = time allowed

Substituting the time allowances in the formula, it will read: (0.336 hour × number of flat truck deliveries) + (0.252 hour × number of lift truck deliveries) — time taken × 0.25 + time taken = time allowed.

The total number of requisitions for industrial-truck service (Form No. 14284) with the proper signatures, will be forwarded each day to the time clerk of Section L-24. At the end of each pay period a total of these requisitions will be sent to the payroll department where group's earnings will be calculated.

This wage-payment plan is subject to revision in case the conditions under which it operates are changed.

Appendix 2

Part: Stators.
Operation: Put materials in stock and supply.
Location: Sections T-20 and T-30 Group No. 1.
Std. Time: In decimal hours.

Std. Time = 0.53A + 0.60B + 0.70C + 0.78D + 0.23E + 0.30F + 0.41G

Symbols:

A = No. 200 CS stator wound and shipped from section T-20.
B = No. 300 CS or No. 12 W.W. stator wound and shipped from section T-20.
C = No. 400 CS or No. 16 W.W. stator wound and shipped from section T-20.
D = No. 500 CS stator wound and shipped from T-20.
E = No. 400 CS stator wound in section T-30 and shipped from section T-20.
F = No. 500 CS or No. 17 W.W. stator wound in section T-30 and shipped from section T-20.
G = No. 600, No. 700, No. 800 CS or type G stator shipped from section T-30.

Note: To compute group percentage, use the following expression.

$(ET - TT)\ 0.25 + TT = TA$ Then $\frac{TA}{TT}$ = group percentage

ET = Established time
TT = Time taken
TA = Time allowed

Reason for Change:

Put materials in stock added, and No. 600, No. 700, No. 800 CS and Type G stators shipped from section T-30 included.

Application:

Applies to all stators shipped from sections T-20 and T-30, and applies to group No. 1 section T-20.

Analysis:

The duties of this group begins in section S where the industrial railway leaves the loaded cars of material required in building stator cores, namely; iron, feet, end shields, frames, etc.

The loaded cars will be pushed on to elevator No. 40 and brought up to section T-20 where the materials will be unloaded and put into stock. The return material, clamps, and boxes will be loaded on the empty cars, and returned to section S, via the elevator.

Further duties of the group will be to supply the various productive groups with all material required and to load the finished stators on to shipping trays for shipment to section E-9.

Procedure:

Group (A) will bring loaded cars from section S to section T, (B) unload and put material in stock, (C) return empty cars to section S, (D) supply building group, (E) put cores into stock, (F) supply winding groups, (G) supply connecting groups, (H) move stators to high frequency test and after being tested (I) load stators on to shipping trays.

Details of Operation:

No. 200 CS, CW, CI, AR, or WW stator

Oper.	Description	Occurs	Time value
A	Bring materials up elevator	1 per stator	0.0200
B	Put materials in stock	1 per stator	0.0200
C	Take empty cars down elevator	1 per stator	0.0150
D	Supply builders	1 per stator	0.0235
E	Put core in stock	1 per stator	0.0316
F	Supply winders	1 per stator	0.1800
G	Supply connectors	1 per stator	0.1000
H	Supply H.F. test	1 per stator	0.1200
I	Load on shipping tray	1 per stator	0.0200

Synthesis:

Std. Time = A + B + C + D + E + F + G + H + I
Std. Time = 0.0200 + 0.0200 + 0.0150 + 0.0235 + 0.0316 + 0.1800 + 0.1000 + 0.1200 + 0.0200 = 0.5301 use 0.53

No. 300 CS, CW, CI, AR, or No. 12 WW

A1	Bring materials up elevator	1 per stator	0.0200
B1	Put materials in stock	1 per stator	0.0200
C1	Take empty car down elevator	1 per stator	0.0150
D1	Supply builders	1 per stator	0.0300
E1	Put core in stock	1 per stator	0.0400
F1	Supply winders	1 per stator	0.2100
G1	Supply connectors	1 per stator	0.1100
H1	Supply H.F. test	1 per stator	0.1300
I1	Load on shipping tray	1 per stator	0.0250

Synthesis:

Std. Time = A1 + B1 + C1 + D1 + E1 + F1 + G1 + H1 + I1
Std. Time = 0.200 + 0.0200 + 0.0150 + 0.0300 + 0.0400 + 0.2100 + 0.1100 + 0.1300 + 0.0250 + 0.6000 use 0.60

No. 400 CS, CW, CI, AR, or No. 16 WW

A2	Bring materials up elevator	1 per stator	0.0300
B2	Put material in stock	1 per stator	0.0300
C2	Take empty car down elevator	1 per stator	0.0200
D2	Supply builders	1 per stator	0.0600
E2	Put core in stock	1 per stator	0.0500
F2	Supply winders	1 per stator	0.2000
G2	Supply connectors	1 per stator	0.1200
H2	Supply H.F. test	1 per stator	0.1400
I2	Load on shipping tray	1 per stator	0.0300

Synthesis:

Std. Time = A2 + B2 + C2 + D2 + E2 + F2 + G2 + H2 + I2
Std. Time = 0.0300 + 0.0300 + 0.0200 + 0.0600 + 0.0500 + 0.2200 + 0.1200 + 0.1400 + 0.0300 = 0.7000 use 0.70

No. 500 CS, CW, CI, or AR

A3	Bring materials up elevator	1 per stator	0.0400
B3	Put materials into stock	1 per stator	0.0400
C3	Take empty car down elevator	1 per stator	0.0300
D3	Supply builders	1 per stator	0.0900
E3	Put core in stock	1 per stator	0.0600
F3	Supply winders	1 per stator	0.2200
G3	Supply connectors	1 per stator	0.1200
H3	Supply H.F. test	1 per stator	0.1400
I3	Load stator on shipping tray	1 per stator	0.0400

Synthesis:

Std. Time = A3 + B3 + C3 + D3 + E3 + F3 + G3 + H3 + I3
Std. Time = 0.0400 + 0.0400 + 0.0300 + 0.0900 + 0.0600 + 0.2200 + 0.1200 + 0.1400 + 0.0400 = 0.7800 use 0.78

No. 400 CS, CW, CI, or AR

A4	Bring materials up elevator	1 per stator	0.0300
B4	Put materials in stock	1 per stator	0.0300
C4	Take car down elevator	1 per stator	0.0200
D4	Supply builder	1 per stator	0.0600
E4	Put core in stock	1 per stator	0.0500
F4	Deliver core to section T-30	1 per stator	0.0400

Synthesis:

Std. Time = A4 + B4 + C4 + D4 + E4 + F4
Std. Time = 0.0300 + 0.0300 + 0.0200 + 0.0600 + 0.0500 + 0.0400 = 0.23

No. 500 CS, CW, CI, AR, or No. 17 WW

A5	Bring materials up elevator	1 per stator	0.0400
B5	Put materials in stock	1 per stator	0.0400
C5	Take car down elevator	1 per stator	0.0300
D5	Supply builders	1 per stator	0.0900
E5	Put core in stock	1 per stator	0.0600
F5	Deliver core to section T-30	1 per stator	0.0400

Synthesis:

Std. Time = A5 + B5 + C5 + D5 + E5 + F5
Std. Time = 0.0400 + 0.0400 + 0.0300 + 0.0900 + 0.0600 + 0.0400 = 0.30

No. 600, No. 700 and No. 800 CS, CW, CI, and Type G

A6	Bring materials up elevator	1 per stator	0.1000
B6	Put materials in stock	1 per stator	0.0800
C6	Take car down elevator	1 per stator	0.0500
D6	Supply builders	1 per stator	0.1000
E6	Put core in stock	1 per stator	0.0800

Synthesis:

Std. Time = A6 + B6 + C6 + D6 + E6
Std. Time = 0.1000 + 0.0800 + 0.0500 + 0.1000 + 0.0800 = 0.41

Inspection:

No inspection required.

Wage Payment:

Indirect standard time.



FIG. 1 MOUNTAINOUS REGION OVER WHICH A TRAMWAY IS BEING ERECTED

The Application of Aerial Tramways to Long and Short Hauls

BY M. P. MORRISON,[1] WORCESTER, MASS.

Aerial tramways are of value where no other means of transportation is possible and also in competition with other methods of transportation. The difficulties of an engineering nature are easily overcome. The advantages over other methods are independence of weather conditions, independence of ground conditions such as crossing streams, roads, ravines, and mountains, thus avoiding expensive tunneling or trestle work, and the easy protection of property by guard screens over railroads, highways, and buildings. With aerial tramways, the length and capacity are unlimited from an engineering standpoint. Tramways have been built up to 54 miles. An extremely long tramway can be built in several sections. There are tramways with a capacity up to 300 tons per hour in successful operation. Extreme length and capacity are sometimes limited from a commercial standpoint, where long railroad hauls are more economical. In the handling of material a small amount of labor is required. A tramway of 200 tons per hour can be operated by one man and a helper, with no rehandling of material. The aerial tramway is applicable for large construction jobs. There is a 220-tons-per-hour tramway for dam construction running 24 hours per day. Among tramways of special design are the tramway at Alabaster, Mich., which carries 300 tons per hour of gypsum rock from a shore bin to a lake dock 6600 ft. out; a tramway at Gerlach, Nev., which carries 100 tons per hour of gypsum rock 5¼ miles to a discharge terminal with the special feature of discharging into a bin or of forming a big stock pile outside of the station. Passenger tramways have not been built in this country to any extent on account of the opposition to this means of transportation.

THE application of aerial tramways lends itself readily to a division of two general classes—one in which the contour of the ground is so rugged as virtually to preclude the use of any other method of transportation, and the other in which the contour of the ground is such that other means of transportation may be used.

The first-mentioned class needs no advocate; it has been thoroughly demonstrated by numerous installations in the United States, in Mexico, and in South America as an economical and dependable method of transportation in mountainous regions, and was largely instrumental in developing coal and mineral deposits that otherwise were inaccessible. The view shown in Fig. 1 will convince that no other method of transportation could be used to convey the ore from the mine to the valley below.

This class of tramway application occasionally presents difficulties of an engineering nature only, such for example as dependable rope-gripping devices to negotiate unusually steep slopes; unusually long spans and the effect of high-velocity winds upon them; negotiating horizontal angles that may be necessary in the alignment of the tramway; conserving the life of the track cables and traction rope, etc.—all of which problems lend themselves readily to a satisfactory solution.

The second division of the application of aerial tramways, that in which other means of transportation may be used and must be regarded as competitive, usually presents few engineering difficulties of design, but, on the other hand, it must stand a comparison with other more orthodox methods on the grounds of economy and reliability.

The aerial tramway starts out with many advantages not

[1] American Steel and Wire Company. Mem. A.S.M.E.

Contributed by the Materials Handling Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

found in other methods; namely, it is independent of weather conditions; snow, sleet, floods, etc., do not interfere with its operation; in crossing streams, roads, ravines, mountains, etc., no bridging, tunneling, or trestle work is required.

Fig. 2 shows all that is necessary to provide protection to a railroad crossing.

The right-of-way is more or less easily acquired, since cable supports are few and far between, and can be so located as to be least objectionable to owners of the intervening land.

Before approaching the economic aspect of this comparison, it is well to discuss briefly the physical limitations of aerial tramways: What is the longest tramway that can be built? What



FIG. 2 GUARD SCREEN OVER RAILROAD AND HIGHWAY

is the greatest tonnage that a tramway will carry? What is the longest single span a tramway may have?

If one merely takes past performance as a guide, he may answer these questions respectively as follows:

There are at least two tramways in the United States, each 13 miles in length; one 21 miles in length in the Andes, and one in Colombia, South America, 54 miles in length; and a large number of tramways in the United States range in length from 2 to 6 miles.

At least one tramway, recently installed, was designed for a capacity of 300 tons per hour, and installations ranging from 50 to 200 tons per hour are quite numerous.

The longest single span, to the author's knowledge, is about 4500 ft. on a tramway of medium-tonnage capacity and is 6500 ft. on a tramway having a very light capacity.

Neither the length nor the capacity of a tramway is really limited since any number of tramway sections can be joined by control and transfer stations, thus giving unlimited length; also very heavy tonnages can be carried by using larger cables, larger carriers, closer spacing of carriers, and building two or more parallel tramways with common terminals; also the length of span is limited only by the height of the cable supports or by the depth of the ground depression to accommodate the deflection of the cables, provided the tension of the traction rope is kept within certain limits.

The limitations of aerial tramways as to length and capacity are therefore not physical but economical, to illustrate which one need assume only an extreme case of an occasional shipment of material over a distance of 300 miles at the rate, say, of $9 per ton of freight, and the other extreme of a constant flow of material at the rate of, say, 300 tons per hour over a distance of three miles.

In the first case the cost per ton-mile would be three cents, but in the second case the railroad expense for switching alone would be greater than the entire cost per ton when carrying this material by aerial tramway.

Here, then, is the outstanding difference between these two methods of transportation; that low rates per ton-mile are obtainable by rail for long distances, but that such low rates do not apply to short hauls of, say, two to six miles; whereas in the case of the aerial tramway, especially designed to carry usually one kind of material in bulk or in containers, such low rates are obtainable for short hauls.

In the case of the privately owned railroad the comparison would have to be made on the basis of the cost of the installation, maintenance charges, rehandling, etc.

In most cases an aerial tramway is designed to carry a constant regular flow of one kind of material taken from a central loading point in bulk or in containers, and consequently in all such cases the tramway is so designed as to handle the entire output with a minimum amount of labor for operation as well as a minimum amount of depreciation.

As an example, a recent installation, in which coal at the rate of 200 tons per hour is transported from the mine to the railroad tipple a distance of about 3400 feet, is operated by one man and a helper, and the operating costs per ton can be estimated



FIG. 3 PROFILE OF AERIAL TRAMWAY IN OPERATION AT ALABASTER, MICH.

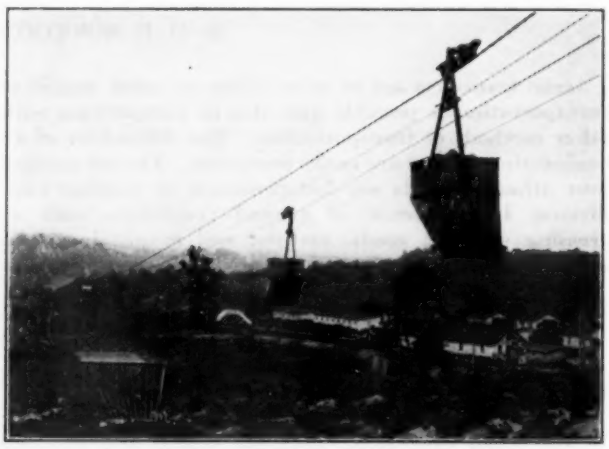


FIG. 4 CARRIER WITH FOUR-WHEEL CARRIAGE, UNDERHUNG COMPRESSION GRIP, AND END-DUMP BUCKET

easily from this. It was possible to accomplish this by means of recently developed automatic devices.

There is usually no rehandling of material where an aerial tramway is used; thus in a recent installation carrying gypsum rock at the rate of 300 tons per hour, the tramway carriers are loaded from a 1000-ton cylindrical bin and discharge their contents into a 10,000-ton bin, distributing the material over the entire width and length of the bin automatically, requiring only the occasional moving of the tripping device to various locations; in another installation even this labor has been eliminated and replaced by remote-control electrically operated trippers.

The object of this article is not to make actual comparisons of the cost of transportation by various methods, but rather to indicate, if not actually delineate, the exact field of tramway application. Such cost data are not readily obtainable for other

methods, but can be estimated easily for any given tramway project from data in possession of reputable tramway builders.

Recently aerial tramways were used in the construction of two notable dams, the Coolidge Dam near San Carlos, Ariz., and the Pardee Dam near Valley Springs, Cal.

In the first instance, sand and gravel were transported a distance of 2000 ft. at the rate of 150 tons per hour, and in the second, the same material was carried a distance of nearly four miles at the rate of 220 tons per hour. In this instance a total of about 1,400,000 tons was carried practically without interruption and with 24-hour-per-day operation, at the end of which time the equipment was still in very good condition.

The future field of application of the aerial tramway may be indicated by one installation in which cinders from a large boiler plant are loaded directly into tramway carriers which carry this waste material to a distant ravine, and another in which coal is carried from the mine direct to the coal bunkers of a locomotive-coaling station located in the coal-mining section of the country.

Mining engineers, as a rule, are conversant with aerial tramways since, as stated, this method of transportation is very often found to be indispensable in rugged, mountainous country, but it is only within very recent years that attention has been given this subject by those engaged in the planning of large construction jobs, power plants, and industrial plants.

It is with the idea of indicating some of the possibilities of tramway application that the following examples are offered:

(1) Aerial tramway at Alabaster, Mich., designed to carry crushed gypsum rock at the rate of 300 tons per hour from a shore bin to a lake dock about 6600 ft. out.

This tramway, as will be seen from the profile, Fig. 3, has eight intermediate cable supports, carried on cribs in the lake. The cylindrical shore bin is of 1000 tons capacity and is equipped with six air-operated bin gates for loading the gypsum rock into the tramway carriers, which are then automatically spaced and dispatched out on the line at exact regular intervals.

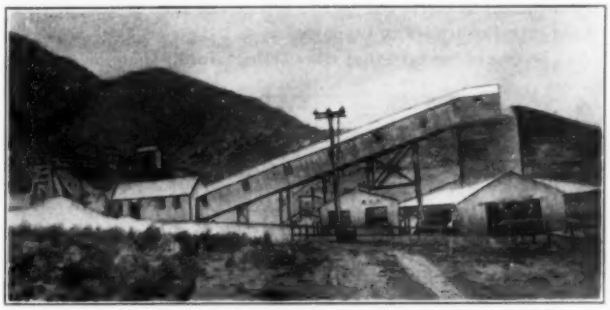


FIG. 6 LOADING TERMINAL OF AERIAL TRAMWAY AT GERLACH, NEV.

The carriers are of the type shown in Fig. 4 and are pendant from articulated four-wheel trolleys. The grips are of the underhung compression type.

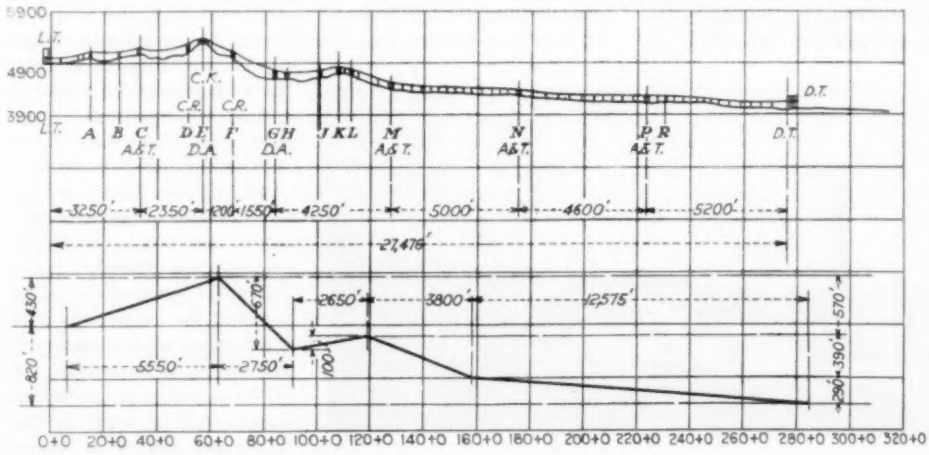


FIG. 5 PROFILE OF AERIAL TRAMWAY IN OPERATION AT GERLACH, NEV.

Mark	Structure	Type	Length	Width	Height	Slope toward loading terminal	Slope toward discharge terminal
L. T.	Loading terminal	Timber	63′ 6″ to center line of bin	27′ 0″	10′ 9″		7.11% up
A	Two bent	Timber	15′ 4″	16′ 0″	23′ 0″		
B	Two bent	Timber	15′ 4″	16′ 0″	48′ 0″		
C	Anchor and tension	Timber	40′ 0″	16′ 0″	30′ 0″	13.36% down	16.5% down
D	Curved-rail support	Timber	27′ 2″	16′ 0″	60′ 0″	31.46% down	12.22% up
E	Double anchor and curved rail	Timber	76′ 0″	16′ 0″	21′ 0″	18.32% down	36.1% down
F	Double anchor and curved rail	Timber	30′ 0″	16′ 0″	22′ 0″	14.2% up	41.35% down
G	Double anchor	Timber	30′ 0″	16′ 0″	44′ 0″	8.15% up	3.35% down
H	Two bent	Timber	15′ 4″	16′ 0″	52′ 0″		
J	Two bent	Timber	15′ 4″	16′ 0″	23′ 0″		
K	Two bent	Timber	15′ 4″	16′ 0″	21′ 0″		
L	Three bent	Timber	24′ 0″	16′ 0″	20′ 0″		
M	Anchor and tension	Timber	35′ 6″	16′ 0″	30′ 0″	14.41% up	12.69% down
N	Anchor and tension	Timber	34′ 0″	16′ 0″	28′ 0″	Level	7.52% down
P	Anchor and tension	Timber	34′ 0″	16′ 0″	27′ 0″	Level	Level
R	Two bent	Timber	15′ 4″	16′ 0″	19′ 0″		
D. T.	Discharge terminal	Steel	59′ about	28′ 0″	45′ 0″ about	Level	

The carriers distribute the rock over a bin on the dock that is about 300 ft. long and about 40 ft. wide; they dump their contents while in motion, and at points determined by the location of the movable automatic bucket trippers; the carriers remain gripped to the traction rope while traversing this bin, and make their turn from the loaded side to the empty return side by means of a circular rail loop placed above a sheave of the same diameter as this loop, and on the face of which the grip jaw rides, disturbing the traction rope very little.

(2) Aerial tramway at Gerlach, Nev., designed to carry gypsum rock at the rate of 100 tons per hour from quarry to plant, a distance of about 5¼ miles.

Fig. 5 shows the profile of this tramway with the summit 1250 ft. above the discharge terminal, and a net difference in elevation between the terminals of 820 feet.

Because of this difference in elevation being in favor of the loads, the tramway is practically neutral, neither requiring nor developing any power; the power developed by the loaded carriers being sufficient to pull up the empties, leaving a surplus that is just about equal to the friction of the entire system. A

motor is used however, for starting the tramway and for maintaining uniform speed.

The loading terminal arrangement is quite similar to that described in the preceding example and is shown in Fig. 6; this figure also shows the general method used in handling the material from the quarry to the tramway bin. A car dumper is shown in the background delivering the rock to a primary crusher, from which it is conveyed to the top of the bin, and from there loaded into the tramway buckets.

At the discharge terminal the carriers dump their load into a

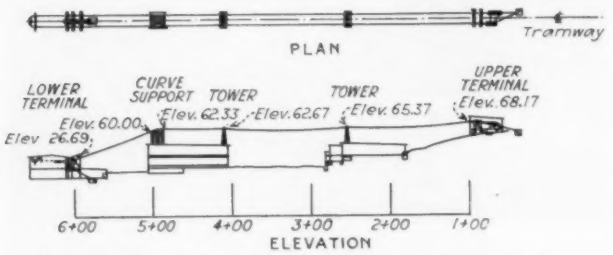


FIG. 7 PROFILE OF AERIAL TRAMWAY IN OPERATION AT SAYLESVILLE, R. I.

small central hopper that feeds the material to an open stock pile. A conveyor running under this stock pile delivers the rock to other crushers.

A revolving crane of large radius is capable of storing a large quantity of rock when quarry production is in excess of mill requirements, and stock is thus accumulated for the use of the mill when the quarry is shut down in cold weather. If it was not for this requirement, the tramway could deliver the rock direct to the crushers in the mill.



FIG. 8 PANORAMIC VIEW OF AERIAL TRAMWAY AT SAYLESVILLE, R. I.

(3) Aerial tramway at Saylesville, R. I., designed to carry rolls of cloth on trucks in an enclosed carrier over a distance of 580 ft. and at the rate of 15 trucks per hour.

This installation is described here by way of contrast to those already described, and to show the application of aerial tramways to special conditions.

Fig. 7 shows the profile of this tramway, and Fig. 8 is a panoramic view of it.

Because of the short distance between the terminals of the tramway and the small tonnage capacity requirements, the tramway was designed as a double reversible system with only two carriers permanently attached to the traction rope, so that when one carrier is at the loading terminal on one track cable, the other is at the discharge terminal on the other track cable. By reversing the direction of motion of the traction rope alternately, a load is sent out first on one cable and then on the other, with the empty returning while the load moves forward.

The panoramic view shows the congested condition of the yard between the building served by the tramway, and it is also apparent that no difficulty is experienced in going over roofs of buildings and entering the carrier into a closed building.

(4) Aerial tramway designed for carrying dynamite "dope" into various mixing buildings.

This type of tramway was developed for the use of a large corporation engaged in the manufacture of explosives, and serves to illustrate further the facility with which this system can be adopted to special and rather intricate requirements.

The primary object in the design of this type of tramway, of which quite a number are now in use, was to secure automatic operation to the greatest degree obtainable, not for labor-saving reasons, but primarily to avoid the use of men who would be in grave danger of an accidental explosion in handling the material.

How well this object was accomplished can best be judged from the following brief description:

The so-called "dope" is used in the manufacture of dynamite, and must be delivered at regular intervals to a series of mixing houses located several hundred feet apart.

This "dope" is handled in cans, each having a gross weight of 150 lb. These cans are loaded into enclosed tramway carriers, provided with hinged doors, and having a capacity of from four to six cans.

The mixing houses are located in a straight line with the loading terminal, and the problem was to connect the loading terminal with all these mixing houses by aerial tramway, and to deliver the dope to any one of the series of mixing houses without manual supervision, without stopping the operation of the tramway, and without impeding the movement of any other carrier to any of the other mixing houses.

An overhead tramway turnout rail was installed at each one of the mixing houses, as shown in the diagram, Fig. 9, and an air-operated rail switch permits the carrier to enter the turnout when closed or to proceed on its way when open.

The air valves actuating these switches are operated by bars which are located at various heights at the series of mixing houses, the one next to the loading terminal being the highest, and these bars are in turn operated by a vertically adjustable bar on the carrier called a "selector" which is set at the loading terminal at the proper height to enter any desired mixing house.

The carrier, arriving at the mixing house for which it is intended, ungrips the rope automatically, and the "selector" engages the air-valve operating lever, which closes the switch and allows the carrier to enter the turnout; it then retains sufficient momentum to engage the lever of another air valve, which opens the switch behind it, and allows the following carrier to proceed on its way; the carrier is brought to rest gently and gradually by the trolley wheels entering into a braking device that wedges the trolley wheels on the rail.

The mixing-house operator, when ready, unloads the cans and sends the empty carrier to the tail terminal, at which terminal the carrier passes around a circular rail loop, and returns on a parallel track cable to the loading terminal to be reloaded. A loaded carrier is dispatched every four minutes.

(5) Aerial tramway designed for carrying a gross load of 34 tons over a single span 2600 ft. long.

Still another special application of the aerial tramway, and one that is unique, is illustrated by Fig. 10.

The problem here was to transfer cars of sawed lumber from the sawmill on one side of the American River Canyon to the other side for storage and shipment.

The transfer car is equipped with rail of the same size and gage as the surface railroad, and the lumber cars are pushed on it after it has come to a stop against the surface rails.

As will be seen from Fig. 10, this transfer cage is supported by eight four-wheel trolleys running on four track cables, and one of the important features of the design was to insure the equalization of tension in these cables so that they may at all times all lie in the same horizontal plane. The trolleys, of course, are articulated so that the weight is equally divided among all wheels, thus insuring a moderate unit wheel load.

The importance of counterweighting the track cables, rather than anchoring them at each end, is here clearly demonstrated; not only would it have been difficult to keep the cables in the same horizontal plane, but the vertical angle of approach to the terminal rails would have been much steeper, as is shown by the fact that as the loaded cage approaches the end of its travel, about 12 ft. of cable is pulled out of the span by the counterweight.

The transfer cage makes the trip across the 2600-ft. span in somewhat less than two minutes, its maximum speed being about 1800 ft. per minute.

Special devices were developed for locking the lumber car to the transfer cage, and various automatic devices were installed for controlling the speed of this tramway.

The two terminals are at practically the same elevation, there being only about 35 ft. difference; the loaded transfer cage on leaving the terminal rails tends to run down the cable slope at great speed, which is checked and held to a maximum of 1800 ft. per minute by two 220-hp. induction motors operating in tandem and acting as brakes; on the load ascending to the discharge terminal an equal amount of power is required.



FIG. 10 CARRIER TRANSPORTING CARLOAD OF SAWED LUMBER OVER DEEP CANYON NEAR CAMINO, CAL.

On approaching either terminal a screw-type limit switch gradually reduces the speed of the motors, and the car enters the terminals slowly, and comes to a stop a short distance from the bumpers. It is then inched into position by an inching push-button.

The drive is located at the discharge terminal, but the wiring is such that the motors can be controlled from both ends; an interlocking system makes it impossible to start the motors from one terminal when the transfer car is at the other.

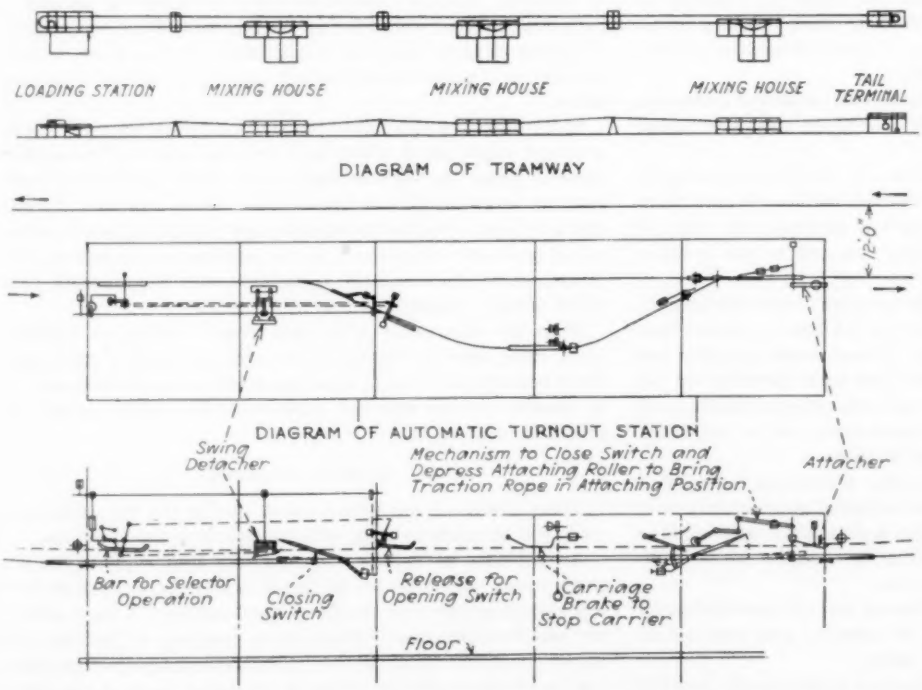


FIG. 9 DIAGRAM OF AERIAL TRAMWAY AND AUTOMATIC TURNOUT STATION IN OPERATION AT PLANTS MANUFACTURING HIGH EXPLOSIVES

PASSENGER TRAMWAYS

This field of application of the aerial tramway, which has had such a remarkably rapid and entirely successful development in European countries since the World War, has not as yet been touched in this country.

In Europe it has served to bring within reach to the general public places ideally located for winter sports, but

inaccessible by any other means of transportation; it has enabled also the average person to scale mountains previously accessible only to a few hardy individuals.

A similar problem exists in this country at various mountain resorts and national parks, but opinion is divided as to the desirability of passenger tramways at such places.

On the one hand there is the argument that these places shall be preserved in their original natural state, and that the feat of climbing a mountain shall remain a feat, an achievement, to serve as a spur in attaining physical perfection; various mountaineer clubs are presumably the most ardent opponents to the idea of making the ascent of a mountain easy and within reach of the average man.

The national park service, of course, is opposed to any idea of commercializing the natural beauties of the various scenic spots, and is particularly fearful of the hot-dog stand and the "scenery hog" that may come along with the passenger tramway.

On the other hand, we have those who argue that the foregoing reasons are not sufficiently valid to deprive the general public of at present inaccessible sites, ideally fitted for winter sports in summer time, and that it is a question also as to whether it is justifiable to create an aristocracy of the physically fit, and to deprive those not so fortunately endowed of the opportunities of viewing scenic spots from vantage points at present inaccessible to them.

It is rather difficult to believe that we shall for very long remain behind Europe in this field of transportation, and it is rather encouraging to think that the large number of such European lines installed within the last decade would tend to indicate their success and desirability.

The passenger tramway projects in Europe presumably had to cope with practically the same objections that are being brought forward in this country, and it is conceivable that in time these objections will not appear to be as serious as they seem to be at present.

The safety of this method of transportation was demonstrated by many European installations, and due credit for it should be given various European governments that have exercised strict supervision over such tramways and demanded from the builders adequate and efficient safety devices.

There are in existence several systems of passenger tramways in Europe, all of which differ mainly only in the means employed to provide adequate safety.

All of these installations are built on the double reversible system, having only one car on each track cable—the cars being spaced so that when one is at the top terminal, the other is at the bottom, and are permanently fastened to the traction rope.

The capacity of these tramways is therefore necessarily limited, but a rope-gripping device has not as yet been invented that would permit, with absolute safety, the automatic gripping and ungripping of the traction rope, and thus make possible the use of a system similar to continuous freight tramways in which many carriers could be used, the loaded ones going out on one track cable and the empties returning on the other.

It would appear at present that only a permanent fastening of the car to the traction rope could be regarded as absolutely safe, and therefore it is doubtful whether a detachable grip such as used on freight tramways could ever be designed to be sufficiently safe for passenger transportation.

The objection that the tramway would mar the natural beauty of the scenic resort where it is to be installed may also not be as serious as it may appear at first sight.

The terminals, if desired, can be located unobtrusively, and the cable span is not an ungraceful structure and hardly visible at a distance.

The cable supports are few and far between and easily can be camouflaged so as to blend in with surrounding rocks or foliage.

On the other hand, it may even be argued that the tramway terminal architecture may be made to conform to the nearby lodges or hotels, in which case, why attempt to hide it?

Several mountain resorts and some of the national parks have been confronted recently by requests for permission to build passenger tramways, and the results will be watched with considerable interest as probably marking the beginning of passenger tramway development in this country.

Discussion

JAMES F. HOWE.[2] One of the most important factors in successful tramway operation is the overhead track cable or the traction rope. Experience has shown that the type of cable known as lock coil, with external surface smooth and each wire locked in position between its adjacent wires, is the best for tramway work. This possesses the greatest number of advantages, among which should be noted smooth surface and wires interlocked so they will not permit a broken wire to strip or work out of position. The smooth external surface reduces wear to a minimum, so that long life should be secured.

Just as the proper design of a tramway is essential for the best results, the design and construction of the track cable have been improved and refined to a high degree of precision. A study of the various shapes of wire possible in locked track cable has led to the adoption of a shape that possesses good locking properties and bending properties, i.e., flexibility and good wearing properties. These wires are laid over a core consisting of one or two sublayers of key-shaped wires, and for the internal member a number of round wires. Each of these intermediate layers of wires must be constructed with the greatest precision, whether round, key, or locked wires. Variation in gage sizes of wires must be kept to the smallest possible amount.

Each wire has a niche which it must just fill if perfect cable is to be made. Shaped wires must not vary in general contour or gage limits beyond very narrow limits, because a summation of a number of plus-variations is sufficient to crowd wires, while a summation of minus-variations will produce an open or loose condition.

Many improvements have been made in locked tramway cables in recent years, all of which have been the result of exhaustive research along the various lines which study has shown would result in lengthened life of track cables. It is true that the prospective user, as well as the existing user of locked tramway cable, is in a position to have the utmost confidence in the performance of such cable when made in accordance with the scientific principles already enumerated.

Thus the uncertainty which has existed with some forms of track cable made to the less exact practice existing some years ago is entirely removed, and entirely satisfactory performance can be assured any one who uses cable made in accordance with the principles referred to.

AUTHOR'S CLOSURE

Many questions have been asked during the discussion, and reply will be made to them without repeating the questions.

Adjustability of Saddles. The saddles that support the stationary wire cables known as "track cables" on the towers have a profound influence on the life of these cables. A fixed stationary saddle under heavy wheel loads produces a "hammer and anvil" effect that results in the deformation and premature breaking up of the individual wires in the outer layer of the cable;

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also, a saddle having a short radius of curvature introduces excessive bending stresses which tend to destroy the cable prematurely.

In a modern, properly designed tramway, therefore, the saddles are made rotatable and rock in their journals with any change in the slope of the cable, thus presenting a yielding surface to the trolley wheels; also these saddles are usually made with a radius of curvature of from 15 to 25 ft., depending on the size of the cable, and of sufficient length such as to prevent the cable from bending over the ends of the saddle when the slope of the cable on both sides of it is a maximum.

Replacement of Worn Cables. Tramway track cables are made up as a single strand, hence they cannot be spliced in the same way as an ordinary wire rope, but must be joined by means of mechanical couplings.

To each end of the cable a half of a coupling is attached having a conical basket into which the wires are spread and held in place by semicircular steel wedges and fillers, thus forming a solid steel cone. One half of the coupling has a right-hand thread while the other is threaded left-hand, and the two are joined by a right-and-left-hand connecting plug.

The track cables do not wear uniformly all along the line of the tramway, but usually wear out first at the supports.

Usually a short piece of about 100 ft. is coupled in to replace a worn section, and the method of coupling varies with local conditions. In some cases the tension can be slacked off, the cable let down on the ground, and the coupling made up, while in other cases it may become necessary to affix clamps to places beyond the worn section, and by pulling these clamps together by means of powerful wire-rope block and tackle produce slack at the coupling place and make the repairs from an aerial platform suspended from the cable.

It is seldom necessary to replace the entire cable, but worn-out or defective sections can be replaced by short lengths as required. The introduction of couplings, when these are properly put on, seems not to affect the life of the cables.

Inspection of Cables. Track cables should be periodically inspected. This is usually done by the inspector standing on a carrier which brings his eyes at about the elevation of the cables; with the tramway running at reduced speed, the cables can be thoroughly inspected.

It also is possible usually to make these observations by climbing the towers and looking over the cables with the aid of a powerful field glass.

Maximum Length of Span. The deflection of a counterweighted cable span varies as the square of the span and also is proportional to the number of carriers upon it, and therefore a long span requires either a deep intervening ravine or very high supporting towers, so that the limitations are physical and not theoretical.

The span being counterweighted, the cable tension remains independent of the length of the span and of the number of carriers upon it.

Corrosion Prevention. The track cables and traction rope of a tramway must be protected from corrosion. In the case of the track cables, this is done by a special carrier containing a suitable quantity of lubricant, which is sent out periodically to make circuit of the tramway. A cam on one of the trolley wheels actuating a valve allows a small quantity of lubricant to be deposited on the track cable with each revolution of this wheel, which also spreads it along the cable. The traction rope is oiled by running it over a sheave immersed in oil in a stationary tank located at one of the tramway terminals.

Cost per Mile. The cost per mile of an aerial tramway varies with the following major factors:

(1) The contour of the ground
(2) The length
(3) The capacity in tons per hour
(4) The weight of the material per cubic foot
(5) Facilities for distributing and erecting
(6) Local costs of labor
(7) Material of structures, i.e., steel or timber.

Since the combination of these factors forms an endless variety and they seldom repeat themselves, it is impossible to state with any degree of certainty just what is the cost per ton-mile.

MH-52-5

Designing for Safety in Materials Handling

By R. H. HUCKE,[1] SCHENECTADY, N. Y.

The author covers the special handling of large cases for shipment. The equipment designed to meet the operating conditions is described, and also the features of safety and speed in handling materials. Every conveyor before installation must pass the inspection of the works engineer, and after installation the system is checked over to see that proper guards and switches are supplied.

UP TO a few years ago very little attention was paid to the materials-handling problem. However, since the war, which killed a large number of men who would naturally come as laborers, and also owing to restricted immigration, materials handling has been getting more and more attention from industrial leaders through the advent of mass production in manufacturing. This company, like all other manufacturers, has been installing equipment gradually for handling materials, both raw and in the process of manufacture.

In the past few years much activity has been centered around the manufacture of refrigerators, which, because of the large production and size and weight of the product, presented an excellent opportunity for mechanical handling. The magnitude of this job can be visualized better by giving a few statistics on the raw material required to keep the production up to schedule.

Approximately nine carloads of insulating materials are handled from the cars to storage or to assembly lines per week. To handle this amount of material, which is only a small part of what goes to make up the refrigerator box, would require a crew of fifteen to twenty men and a fleet of trucks. With a conveyor system four to six men handle all of the material, and this also eliminates congestion. The manufacture of the refrigerator box requires a large tonnage of steel which is fabricated into shape, after which it is prepared for painting and enameling. As soon as it is finished, ready for painting, it is suspended from an overhead chain which carries it through the several finishing operations, through the ovens, and directly to the assembly floor. This chain conveyor is approximately 5000 ft. in length, and this has permitted reducing the amount of material in process to a point where the manufacturing and assembling can be carried on in a floor space considered entirely inadequate with any other means of handling the parts.

The assembly is organized in a continuous straight line on a moving apron conveyor to a point where it is ready for shipping. At this point another conveyor takes the packing cases from the carpenter shop to the assembly line, where the units are completed and made ready for shipment. At this point the boxes are dropped into the packing cases and carried to the shipping platform by means of a conveyor which is described later. Bearing in mind that these units vary in weight from 400 to 1100 lb. each, this conveyor has many novel features.

When this company entered the refrigerator field with an all-steel cabinet, safety was an important factor. In the design the cabinet featured the art of preserving food safely with good appearance. With the production of these cabinets at the Schenectady Works, the safety thought was continued. Safety to the employees, and also in the handling of the cabinets, as in the beginning of their manufacture, still prevails today.

During the beginning of the refrigerator-cabinet production, conveyors and other mechanical-handling equipment played a small part in the picture as compared with their application to the present layout. There are several reasons for these changes from simple to elaborate handling systems. In the beginning the output of cabinets was small and did not warrant the expenditure of large sums of money for handling equipment. As the production on these cabinets increased, and with the addition of three larger-size cabinets, it became necessary to improve the handling facilities of the department. This was done without limiting any expense in making the new conveyor systems as efficient and safe as possible.

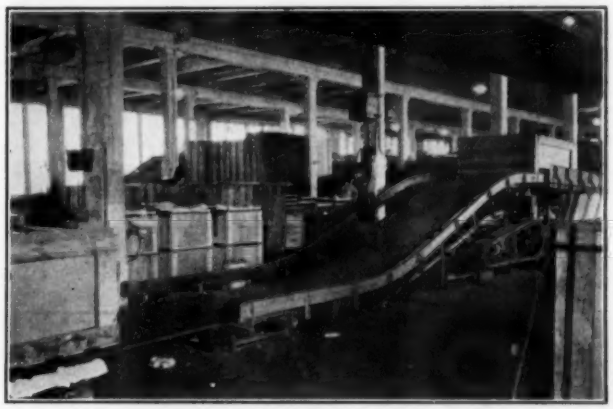


FIG. 1 LOOKING FROM THE END OF THE TWO-DOOR CABINET-ASSEMBLY LINE TOWARD THE POWER INCLINE APRON-TYPE CONVEYOR

A description of the new shipping-conveyor system for handling the refrigerator cabinets is interesting because of its safety features. The question that may be asked is: What are the duties of this new conveyor system, and how are they accomplished? The duties are to convey the cabinets from two similar cabinet-assembly lines on the second floor of the building down to the shipping platform and then to the freight car. The one line conveys large cabinets; the other, small cabinets.

These cabinet-assembly lines on the second floor are in parallel, approximately 40 ft. apart, and run longitudinally with relation to the building. One is used for the assembly of the one-door cabinets; the other, for the two-door cabinets. The shipping platform is located along the east side of the building and is long enough to accommodate six freight cars.

The operation of the new shipping-conveyor system begins with receiving the two-door cabinets in their shipping crates, backs down, and feet at right angles to direction of travel. They are conveyed from their assembly line in this position by means of a power-driven conveyor of the inclined apron type to a section of roller gravity conveyor. (See Fig. 1.) These cabinets, while still on the roller gravity conveyor, make a 90-deg. turn and then head across the second floor to an opening in the wall of the building. This section of roller gravity conveyor is not at right-angles with relation to the one-door cabinet assembly line.

The one-door cabinets are received from their assembly line in shipping crates, with backs down, and feet pointing in direction of

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[1] General Electric Company.

Presented at the Third National Materials Handling Meeting, Chicago, Ill., March 5 to 7, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

travel. In this position they are conveyed to the same section of roller gravity conveyor as the two-door cabinets by means of an apron-type conveyor. An interesting feature of this part of the system is the simple automatic arrangement for the transfer from the apron-type to the roller-type conveyor at right angles, and at the same time changing the direction of travel of the one-door cabinets from a longitudinal to a transverse position on the section of roller gravity conveyor. This is accomplished by a series of power rollers, set in such a manner as to control accurately the direction of the one-door cabinet until released to the roller gravity conveyor. The one-door and two-door cabinets

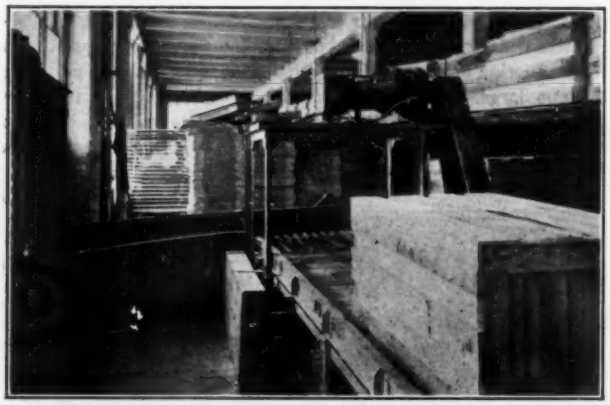


FIG. 2 TRANSFER POINT FROM ONE-DOOR CABINET-ASSEMBLY LINE TO ROLLER GRAVITY SECTION OF CONVEYOR
(Wall opening to the left.)

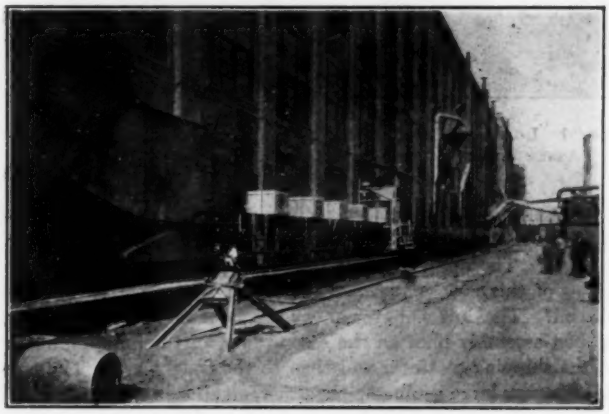


FIG. 3 GENERAL VIEW OF THE SHIPPING PLATFORM

are now on the same conveyor, with their feet at right angles to the direction of travel.

All cabinets, after passing through the wall opening on the roller gravity conveyor, ride a 90-deg. gravity roller curve which delivers them to an inclined power apron conveyor. (See Fig. 2.) This conveyor is in line with the shipping platform. The cabinets are carried down the incline on the apron conveyor to a power roller flight conveyor, which extends the full length of the shipping platform. (See Fig. 3.) This type of conveyor was employed to furnish ample storage of cabinets while the freight cars are being shifted. This is essential, as production must not be interrupted while the loaded cars are being removed from the siding and replaced by empties.

The frame structure of the power roller chain conveyor is so constructed as to carry rails on which two power-propelled semi-automatic tilting devices, called unloaders, run. (See Fig. 4.) The purpose of the unloader is to remove the cabinets from the power roller chain conveyor and deliver them to the freight-car floor in an upright position, with feet down. (See Fig. 5.) Each unloader is equipped with an individual motor drive, which propels it along the power roller chain conveyor through a rack and pinion. (See Fig. 6.) This drive is controlled manually so as to permit the operator to move the unloader to the freight-car door, no matter where the car may be stationed along the siding.

The unloader consists of two distinct operating parts—the transfer arm, or kick-off, and the tilting mechanism. (See Fig. 6.) These two operating parts are equipped with separate motors and worm-gear reduction units. (See Fig. 7.)

As each size cabinet is of a different width, and all cabinets must be diverted from the power roller chain conveyor approxi-

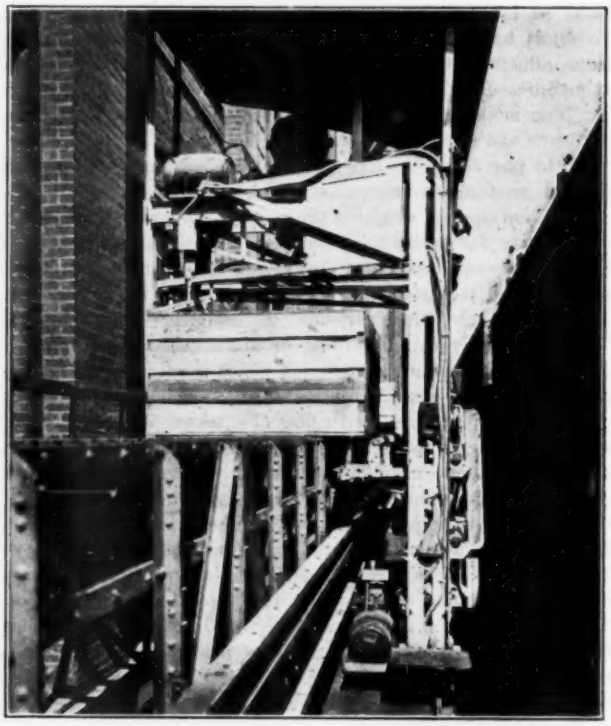


FIG. 4 SIDE VIEW SHOWS CRATE PASSING THROUGH UNLOADER

mately at the center of the unloader, a special electric switch was designed, called the selector. This selector consists of several contacts, one for each size of cabinet. Each of these contacts is connected to a limit switch, which is mounted on the unloader frame and set to start the transfer arm at the proper time for each size of cabinet.

The arm on the unloader is used to transfer the cabinet from the power roller chain conveyor to the tilting mechanism. This is accomplished in the following manner: The cabinet, still on the power roller chain conveyor with its feet pointing toward the freight car, enters the unloader and engages the transfer arm. This automatically sets the contact, or selects the limit switch which is to divert the case. When the case has thus set the selector and depressed the proper limit switch, the transfer arm motor starts and, in turn, through a crank and lever movement, diverts the cabinet from the power roller chain conveyor to the tilting mechanism.

When the transfer arm has reached the end of its outward stroke, it closes a limit switch, which starts the motor oper

ating the tilting mechanism table on its downward movement. This movement is through a worm reducer, pinion and gear segments, which causes the table to move through an arc of approximately 90 deg. The cabinet is lowered to the freight-car floor on its feet and is manually removed from the tilting mechanism table and trucked to its position in the car.

For safety, the tilting mechanism does not return to its loading position automatically, but by the operator pushing a starting button. A complete set of emergency buttons is also provided so that the unloader can be controlled through them temporarily, in the event of failure of a limit switch. Lights are mounted on the loading-machine frame for illumination at night.

When it is desired to operate the two unloaders simultaneously, the cabinets may be "by-passed" through one unloader to the

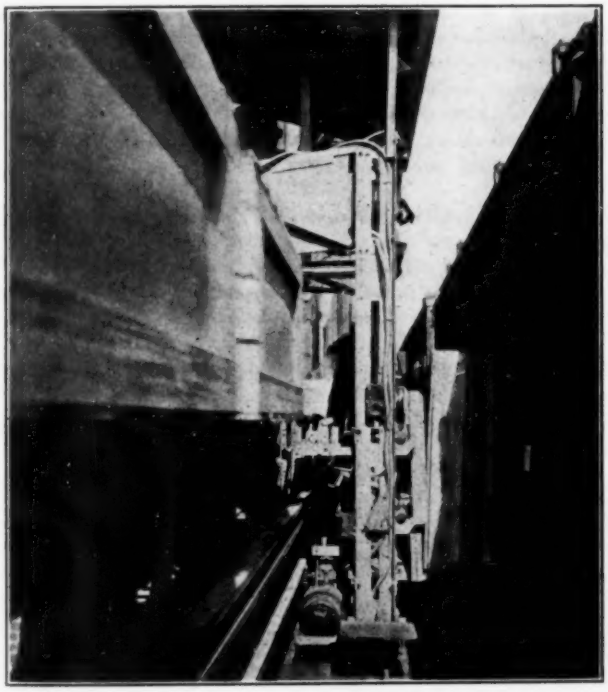


FIG. 5 CABINET DELIVERED TO FREIGHT-CAR FLOOR

other by the operator throwing a switch. This is usually done when more than 50 cabinets per hour are being loaded.

The unloaders are the main feature of the entire conveyor system because of the efficient and almost human manner in which they accomplish their task. This was made possible by a series of specially designed selectors, limit switches, conductor rails, contacts, and motor controls, in combination with ingeniously applied mechanical movements.

With this new conveyor system, a carload—consisting of 51 single-door cabinets, weighing approximately 400 lb. each—was delivered to the freight car in 35 minutes. The only help required was two men in the freight car. This is about half the time and half the number of men formerly required to handle the same number of cabinets. The two-door cabinets, weighing 800 and 1100 lb., respectively, are handled with ease by the new conveyor system. Formerly these cabinets were placed on a truck and lowered to the first floor by a platform elevator, and then trucked to the freight car. This method was a laborious one and required the services of an additional crew of men.

In commenting upon this new conveyor system, it may be said that it has helped to increase and hasten the shipping facilities of the department. The crated cabinets are handled from their assembly lines to the freight cars with the utmost safety. Safety, also, has been realized by reducing to a minimum the human element involved in operating the system. This we

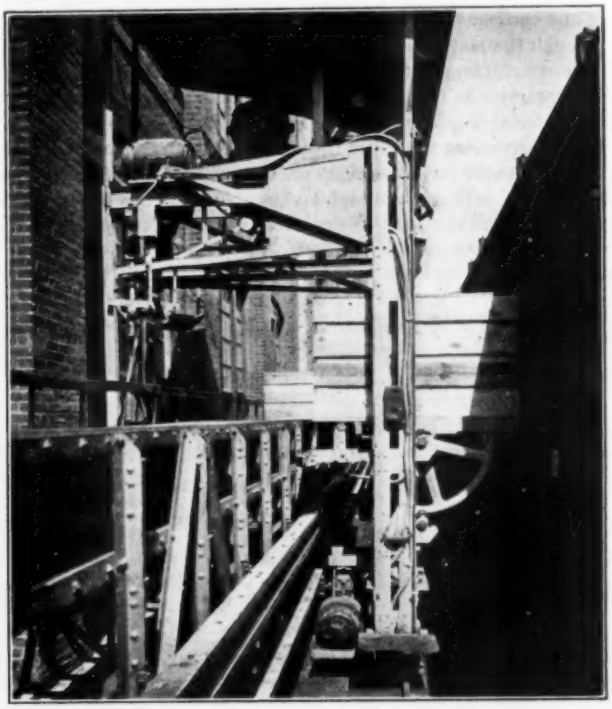


FIG. 6 SHOWING CABINET TRANSFERRED TO THE TILTING MECHANISM

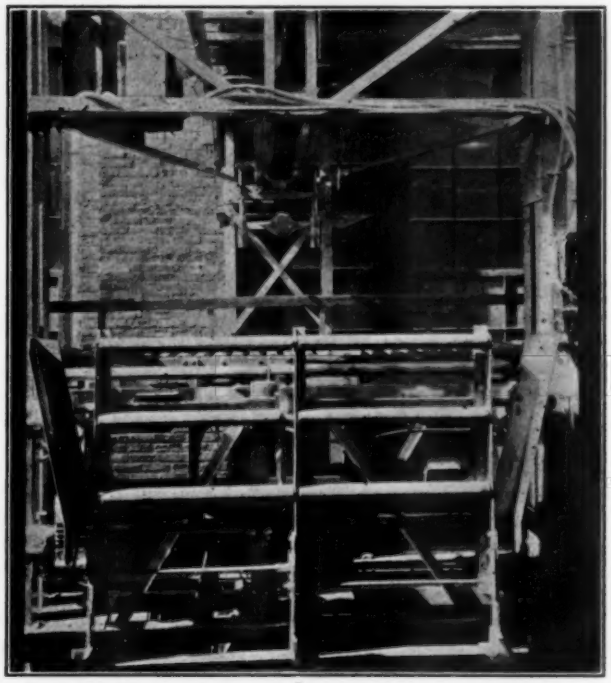


FIG. 7 VIEW OF UNLOADER FROM FREIGHT-CAR DOOR

accomplished in large measure by applying the electric equipment that controls the movement of this conveyor system.

Another feature that should be mentioned is the fact that all the conveyors in the system are properly guarded to insure safety to the employees.

This conveyor system is one of many in the Schenectady Works of the company that are doing their work efficiently and safely through the help of electricity.

In concluding, it may be stated that the following procedure is in practice at the Schenectady Works in the selection and use of material-handling equipment: To help insure safety, all layouts involving the use of conveyors are submitted to the works safety engineer for inspection. A thorough check, from a safety standpoint, is thus given each layout. No conveyor is permitted to be installed until the works safety engineer is satisfied that it will be safe. After the conveyors are installed, another inspection is given them to further the cause of safety before they are put into final operation. No expense is spared in the use of guards and safety switches.

Only designated employees are permitted to operate the conveyors, and they are instructed at all times to play safe in their work. Accidents result in a loss of time and money to both the injured employee and the company because the amount of compensation received cannot equal the worker's regular earnings, and the cost of compensation represents an expense that must be added to the business. The work of properly promoting the interests of safety is important, and the company realizes that it pays to give considerable attention to this item.

MH-52-6

Recent Developments in Material Handling at the Western Electric Company's Merchandise Buildings at Kearny, N. J.

By C. K. PEVEAR,[1] KEARNY, N. J.

A description is given of the Western Electric Company's merchandise buildings at Kearny, N. J., their purpose, and the methods used in material handling in these buildings. A thorough study was made of the purpose of these buildings, the type of the material to be handled, and the possible future changes that might be made in the amount of work to be done and the dimension of units handled. Then the warehouse activities were laid out, and a building was designed to enclose them. Approaching the problem in this manner provided unusual design opportunities not generally met, as in most cases equipment has to be fitted into an existing building.

THE Western Electric Company at its three plants (Hawthorne, Kearny, and Point Breeze) manufactures telephone apparatus and delivers it to the Merchandise Department's three warehouses at the same places. The Merchandise Department in turn receives, packs, stores, and delivers this material to the 32 distributing houses. These distributing houses receive the material in wholesale lots, and then select, ship, and deliver the apparatus to the telephone companies in retail amounts.

At the present time the Kearny Manufacturing Department is called upon to produce approximately 20,000 different items. Some of these items are piece parts, which, when assembled, make up the larger units. The Merchandise Department is required to stock approximately 9000 items. These items vary in weight from less than an ounce to a ton; they vary in size from a piece as small as a pinhead to units 10 ft. long, 8 ft. high, and 6 ft. wide.

The Kearny Merchandise Department may receive an order for one of these piece parts or the order may call for a new telephone exchange. One piece part would probably be for repair of some old piece of equipment that is discontinued and therefore is not stocked, and it would be ordered from the Manufacturing Department; while the order for the new exchange would be broken down into the parts that are stocked ordinarily and the parts that it is necessary to manufacture. This order for an exchange has to be almost entirely accumulated in the warehouse before shipment can be started to the building where the exchange is to be installed. This accumulating period may be from three to six months.

The value of the material stored is approximately $1 a pound, and often there is $10,000,000 worth of stock and of partially assembled switchboard jobs on hand in the Kearny buildings.

Description of Buildings

Although they were not considered first when the layout was being made, a general description of the buildings will be necessary so that the references to floors, balconies, auto courts, etc., will be understood. (Figs. 1, 2, and 3.)

Building 71. Building 71 is a multistory building, 300 ft. long by 100 ft. wide with 20-ft. bays, containing eight floors and a basement. The second floor is really a mezzanine floor; it has many large openings and is actually a vertical extension of the first floor. The ceiling heights of Building 71 are so designed as to get the greatest use of the cubic contents of the building; 11 ft. floor to floor with floor slabs of 9 in., which makes the ceiling a height of 10 ft. 3 in. Thus, with the sprinklers and 18-in. clearance under them there is sufficient height for 8-ft. piling, which height is all that the average man should be asked to stack boxes unaided.



Fig. 1 Merchandise Buildings 71 and 72, Taken From the Southeast Corner

The first and second floors are used for receiving, packing, checking, and packing material storage and also the sealing and nailing operations. The remainder of the floors in Building 71, from three to seven, are used for the storage of standard packed stock, and along the south side of these floors are placed the broken-package racks.

On the top floor are the offices. Over the center section is a turret 13 bays long and 3 bays wide, with trusses spanning 60 ft., leaving this area without posts and lighted on four sides by high windows. In the low section of the top floor the private offices, toilets, lockers, and women's rest room are located. The plastered trusses act as baffles for noise and prevent echoes.

The basement is used for the storage of excess apparatus, packing material, and has a record vault. Elevators and conveyors serve this area.

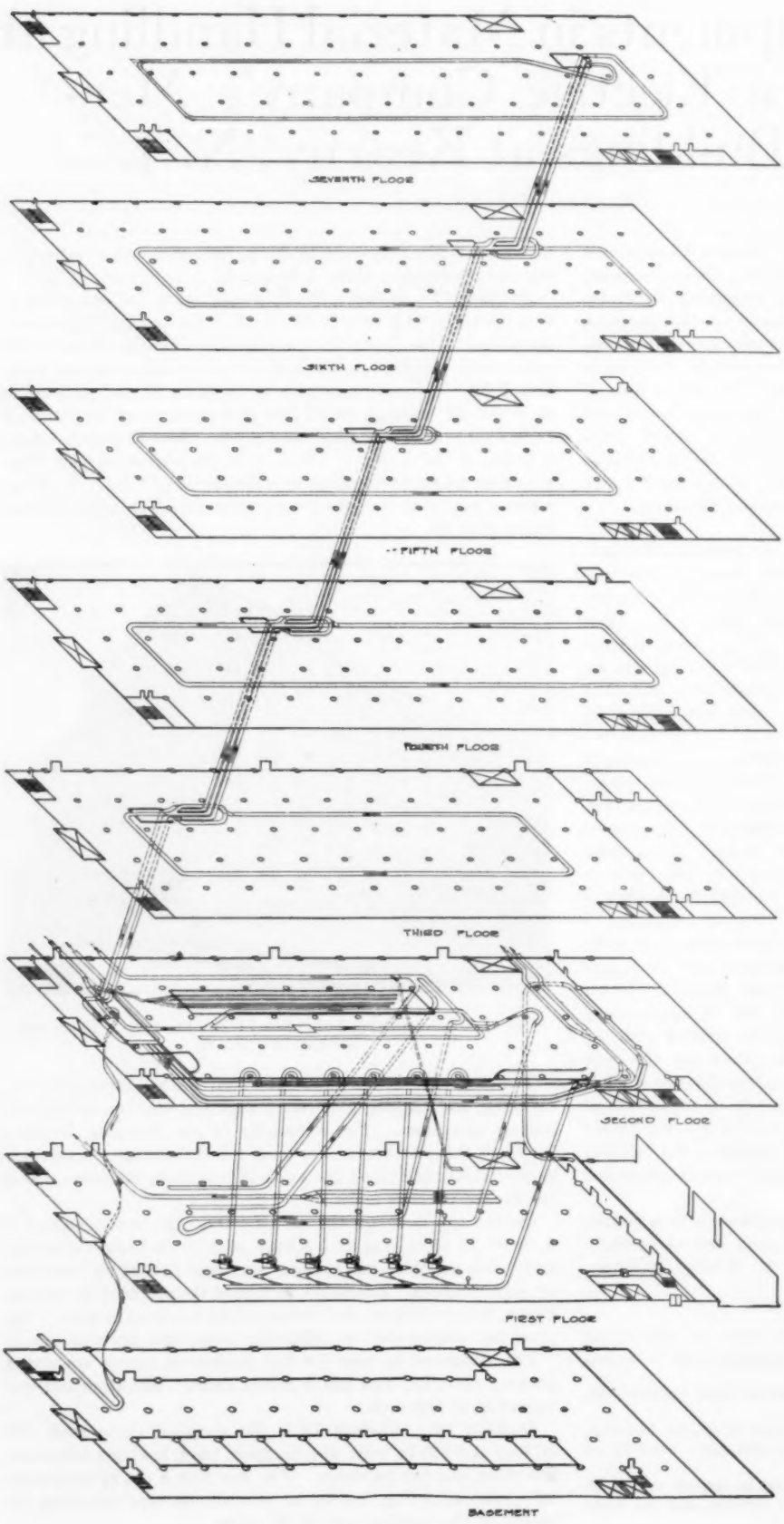
Building 72. Building 72 is the so-called crane shed, 300 ft. long and 100 ft. wide, also on 20-ft. bays, having a basement, first floor, and two balconies. The first floor is cut up lengthwise by a railroad siding, leaving on one side an area extending the length of the building and 20 ft. wide.

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[1] Assistant Distribution Engineer, Telephone Sales Department, Western Electric Company.

Presented at the Third National Materials Handling Meeting, Chicago, Ill., March 5 to 7, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.



The first balcony is on the same level as the second floor of Building 71 and extends from the wall of Building 71 to within 3 ft. of the railroad track. The second balcony is on the same level as the third floor of Building 71, extending from the wall of Building 71 over the railroad track some 8 ft., leaving a long slot between the second balcony's edge and the building wall approximately 12 ft. wide. This balcony is also cut off on the west end so that the second balcony and railroad track are exposed.

The first floor is used primarily for shipping, also for some carload receiving of apparatus and excelsior. The first balcony is used for the accumulation of small miscellaneous items on switchboard jobs and the manufacturing of plywood boxes and panels. The second balcony is used for the accumulation of bulky items such as switchboard jobs, as well as switchboard, power, and lead-covered cable, and has a 500-lb. floor load with a piling height under the crane of 35 ft.

The basement is used for the storage of excess of lead-covered cable, iron work, and slow-moving material. Elevators and crane serve this area.

Truck Courts. At the east end of Buildings 71 and 72 are automobile truck courts extending the width of the buildings, 100 ft. They are entered by three large Kinear doors, two approximately 40 ft. wide and one 20 ft., each court having a capacity of 10 trucks. These doors are electrically controlled from a shipping office, which is located between the two courts on the second floor level and has windows looking out on both and a periscope toward the front; with these windows a clerk can control the placing of the auto trucks and keep the Kinear doors closed in inclement weather.

Crane. The first floor and balconies in Building 72 do not extend to the east wall but are 40 ft. back, so that the crane, which extends the length of the building, is able to place incoming material on the second balcony, one end of the first balcony, on several places on the first floor, and to remove or place material on all of the trucks in the court at the east end. The crane also can place bulky boxes alongside all the cars and can reach down to the first floor and

FIG. 2 (*Left*) ISOMETRIC DRAWING SHOWING CONVEYOR LAYOUT IN BUILDING 71

basement through a hatchway and trapdoor. It can land material on the fourth and fifth floors of Building 71 on the east end as there are small hanging balconies extending out from the wall of 71 on these floors.

There is a sidetrack along the north side of the crane shed building, and the doors in the north wall of this building at the first-floor level are placed so that six cars can be spotted on this track. Thus, the crane can service all the cars on the outside track, as well as those on the inside.

Bay Numbering. All the area in both buildings, with the exception of that occupied by offices, is definitely numbered. On each floor in Building 71 there are two lengthwise aisles which are the streets that the bays face on; the bay numbers have four digits; the first showing the floor (the letter "B" showing the basement), the second digit showing the row of bay numbers starting from the south, the third and fourth digits showing the bay number starting from the east with the number 11; thus 3211 is the third floor, second row, and first bay. The scheme of bay numbering is carried out on the areas of building 72, starting with row 5, so that the number 2514 is the first balcony, or second floor, first row, and fourth bay.

Painted on the inside wall of the crane, Building 72, there is a 2-ft. wide black stripe, about 35 ft. from the second balcony floor. On this stripe are painted the bay numbers, two numbers to each building bay. (Fig. 4.)

On the under side of the crane girders are painted in white the row numbers on 10-ft. centers. Thus, if the area assigned to a box is 832, the crane moves out to row 8 and down to bay 32, and as the row and bay limits are defined by lines on crane girder and wall, the operator does not have to see marks on the floor, but keeps his cables within these limits and deposits his box in the assigned area very easily.

Heating and Ventilation. The building is entirely heated by unit-type heaters, controlled by thermostats, and during the summer the apparatus is used for cooling and ventilation. On the third to the seventh floors are placed large openings, 5 by 6 ft., three on each floor, between the crane building and the multistory building. These are guarded by heavy screening as well as firedoors, and when opened in the summer time have a remarkable cooling effect upon the temperature of these floors.

Handling of Material

At Hawthorne and at Kearny the buildings are so separated from the manufacturing buildings that automobile trucking is required. It may seem peculiar at a first glance that the buildings are not attached so that the delivery of this vast quantity of material can be made by conveyors or electric trucks. However, because of the tremendous quantities and number of different articles made, manufacturing operations are necessarily scattered. In each building material is brought down to the first floor and loaded on auto trucks at different loading platforms. When these auto trucks are unloaded and received by the Merchandise Department, the material is divided into two classes—large bulky items and small items.

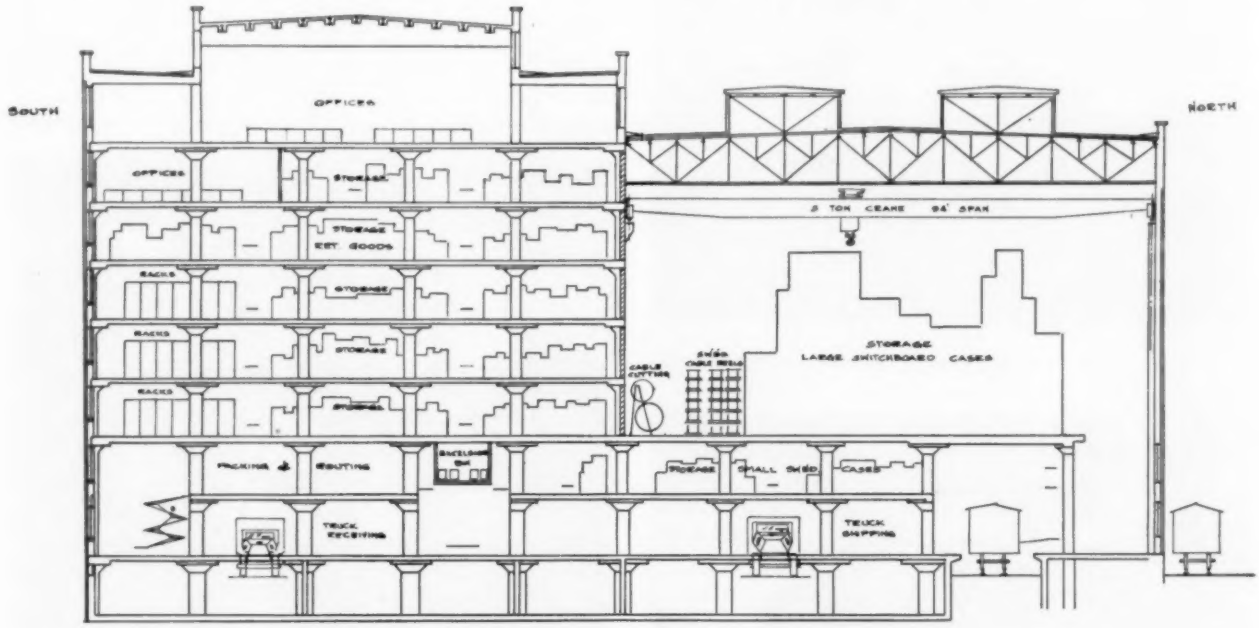


FIG. 3 CROSS-SECTION SHOWING ELEVATIONS OF BUILDINGS 71 AND 72

Bulky Material. Bulky items are brought into the warehouse on the east end of the first floor of the multistory building. These are, for the most part, on platforms and are deposited momentarily on the floor and very close to the doors leading from the automobile court. There is installed a tramrail hung from the ceiling, which has a floor-controlled electric hoist and the carrier pushed by hand. The larger and heavier material is handled entirely from the platforms to the storage conveyor by this tramrail, the operation being as follows:

A platform with its load is deposited approximately under the center of a branch of the tramrail. A special tackle with a very large adjustment is hooked on the apparatus, which is hoisted and pushed along the rail through switches, so that it is suspended over either of the three storage conveyors. The bottom of a box is sent down from the floor above and is placed on a pallet conveyor. Then the apparatus is lowered to this box bottom, which becomes a skid. A considerable amount of this apparatus is of such size and rigidity that it can be lowered into a completed box by this carrier, and then packing details are wedged and nailed in place so that the apparatus becomes very solidly packed. (Fig. 5.)

The pallet-type power conveyor starts at floor level and ascends

at a gentle slope until it is approximately 3 ft. high. There, a box or loaded skid runs down the gravity storage lines, which extend some 100 ft. There are three conveyor lines of this type running parallel with each other and very close together, so that there is considerable storage before the actual packing and nailing conveyor starts. There is a three-way switch connecting the three storage lines with the single packing line. The packing line consists of a three-rail roller conveyor, 11 in. off the floor, one side of which is a live roller conveyor with snub rolls underneath one side, bringing the moving belt to bear



FIG. 4 CRANE AREA SHOWING BAY NUMBERING SYSTEM

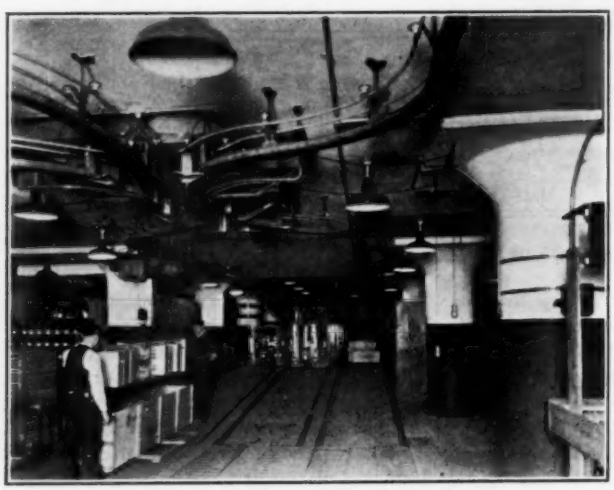


FIG. 5 BULKY ITEM HANDLING TO PACKING STORAGE LINES

on the under side of the upper rolls. The speed of this conveyor is approximately 8 ft. per min., and the packers, who are really box assemblers, can do their work as the apparatus and skid move by them. The sides, tops, and ends, in a majority of cases, are plywood panels and are delivered to the packers on gravity conveyors running down from the second floor through a large opening approximately 120 ft. long by 20 ft. wide. This opening enables the box suppliers working on the second floor, where the packing material is stored, to see the storage lines below and be able to send down on the conveyors the proper materials to make up the boxes in their proper sequence. (Fig. 6.)

At the end of this general packing line the conveyor turns at right-angles to the marking and scale section, and then goes through a large opening in the wall into the so-called crane shed, Building 72, where the majority of this large material is stored. Over this conveyor is a hatchway or opening in the balconies above, so that the crane can reach down through these balconies and remove the boxes from the conveyor.

When this large material is received from the Manufacturing Department, it has attached to it the receiving papers, which give a description of the material and the order number on which it applies. A copy of this ticket is removed and sent by means of a pneumatic tube to the recording department, where the receipt of this material is entered on an accumulation sheet, one of which is started for each switchboard job. This job may be one which is "shipping," that is, the first shipment has been made and all subsequent material is shipped at once. The receiving ticket is so marked and a stencil is cut, then both are sent by pneumatic tube to the marker's position and held there until the box comes by, when it is addressed according to the shipping information. If, however, the job is being accumulated, then the clerk gives it a number which designates the area assigned to the accumulation of this job and it is sent by pneumatic tube



FIG. 6 GENERAL PACKING CONVEYOR

to the marker's position. The marker places this assigned area number on the top of the box, and this, in turn, informs the crane operator exactly where the box is to be placed.

The crane requires a word of explanation. The cab position is unusual, as it is mounted directly above the hook and, in fact, is a part of the hook, as the top of the shank above the ball race is a large plate with holes in it and becomes the bottom of the cab. The operator sits down and his feet rest on this plate, so that he can swing the hook and load by pushing the plate and at the same time look through the slots or over the edge of the floor and see the position of his load.

The control of the crane is entirely within this cab and is accomplished by pilot circuits through relays. The hoisting speed is 150 ft. per minute, which is necessary because a lift of 60 ft. must sometimes be made before the crane can travel in the other directions.

It was necessary for the operator of this crane to be on the hook, for he must unfasten the tackle from the box and also attach it when loading. Floor men could not climb to the tops of these piles as some are 35 ft. high, and many ladders, aisles, and men would be required, as the crane very seldom has two boxes going to the same bay in succession.

Small Material. The smaller material is sent over from the Manufacturing Department in containers which are approximately 24 in. long, 16½ in. wide, and 6 in. deep. These containers are usually placed on platforms or on shelf trucks. When they arrive in the Merchandise Building, they go to the checking department on the first floor, which not only checks the receiving ticket for quantity and kind, but also sorts the material out into two classes—one to be packed and sent to stock, and the other to be placed in racks as non-stock items awaiting shipping instructions. When these instructions are received, the material is sent by means of dumbwaiters to the second floor, and the miscellaneous checker packs them for shipment. The first class is then packed on the standard packing line. The checking operation, as described, especially on stock items, is really a part



FIG. 7 STANDARD PACKING LINE SHOWING EMPTY BOX LINE HUNG FROM CEILING

of the packing operation, inasmuch as it is checked and packed at the same time. (Fig. 7.)

The foreman of the standard packing line reviews the material to be packed every hour and makes out a schedule calling for the number, size, and order of the boxes he requires. The empty boxes on this schedule are sent from the second floor to the first floor on a conveyor, which runs along the ceiling of the first floor for a considerable distance, then turns and continues at a convenient height for the packing operations. This conveyor provides enough room for the storage of a complete schedule of empty boxes.

The packing line is rather unusual in design. At first glance, it appears to be a regular flat roller conveyor, but underneath its length runs a belt supported on snub rollers in a frame. When the motor is started by means of pushbuttons along the side of the conveyor, the belt moves. At the same time, a second motor is put into operation; it elevates the frame and snub rollers, until the belt is in contact with the underside of the conveyor rollers, thus making the line a live roller conveyor. When the belt is raised to the required height, the second motor automatically shuts off. When the stop button is pressed, the belt stops and the second motor is started, which



FIG. 8 DISPATCHER'S POSITION

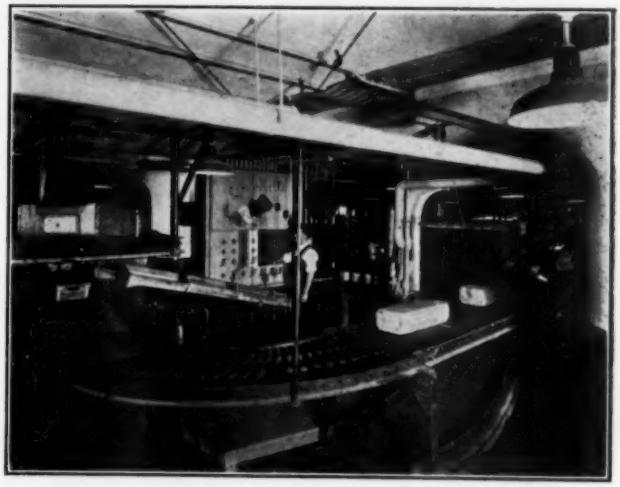


FIG. 9 SIGNAL AND CONTROL PANEL

lowers the frame and snub rollers and then automatically shuts off.

The conveyor is used in the following manner: The skids loaded with containers of the same kind of apparatus are placed alongside of the conveyor. The motor is started, bringing the

empty boxes along the conveyor opposite the skids, then it is shut off. The packers spread the boxes and the containers alternately on the conveyor. This they are able to do easily, as the rollers are free from the belt. Then they pack the boxes, the belt is started up, and the empty containers and full boxes go down the line to the marker and scale section, where the empty



FIG. 10 BOTTOM OF CONTAINER

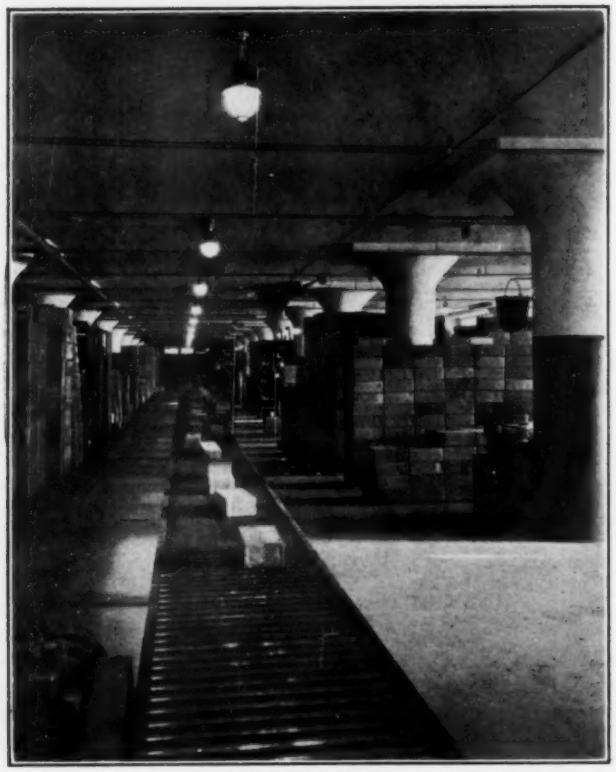


FIG. 11 SOUTH SIDE OF TYPICAL FLOOR LOOP

containers are removed, the boxes are marked by a stencil showing their contents and the bay number where the stock is stored, and they are then weighed. This same movement of the belt brings a new lot of empty boxes, thus completing the cycle.

When the second cycle is started, the stenciled boxes run on a belt which takes them to the second floor, where the conveyor turns back and runs directly overhead to the sealing or nailing machines, according to whether they are corrugated-paper or wooden boxes. The switch making this division is controlled from the first floor at the marker's position.

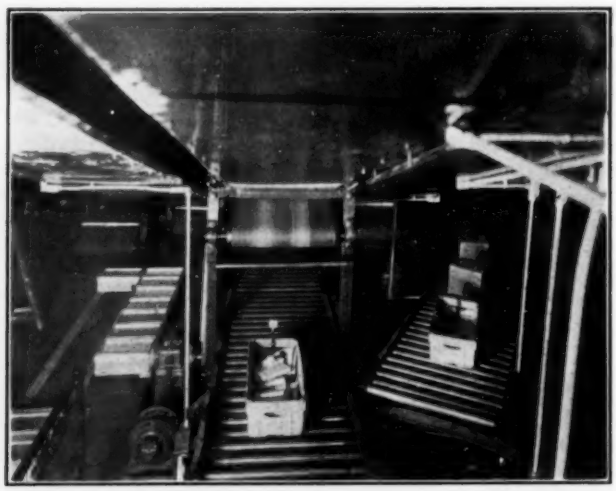


FIG. 12 AUTOMATIC SWITCH



FIG. 13 METHOD OF DRIVING LIVE ROLLER CURVE

SELECTING AND SHIPPING

The orders are received by mail from the distributing houses and are edited, typed, and sent out for either immediate selection or manufacture. Those for selection are sent to the warehouse office on the third floor, where they are sorted for location of

material and sorted so as to get like addresses together and stencils cut for all shipping orders.

Dispatcher's Position. Orders are sent by pneumatic tube to the dispatcher. His position on the second floor is the heart of the entire system. Here the incoming small packed boxes are dispatched to their appointed areas. If they are to be shipped, they can be so switched as to go directly to the correct car or truck by dispatcher. The incoming material arriving by car also passes this position and can be directed to all areas. (Fig. 8.)

There is a large signal board in front of the dispatcher's position which is laid out to look like a bird's-eye view of the critical points of the conveyor system, and by a number of different colored electric lights in the slots, the dispatcher can see whether the distant belts are running, what position the switches are in, and how many and where the boxes are that he is sending out. (Fig. 9.)

Just below this signal board are banks of electrical push-buttons controlling remotely all the belts and switches which the board pictures in miniature, so that the dispatcher has a visual check on the result of his manipulation of the switches.



FIG. 14 GATE SECTION IN RAISED POSITION



FIG. 16 AUTOMATIC "Y" INTERSECTIONS

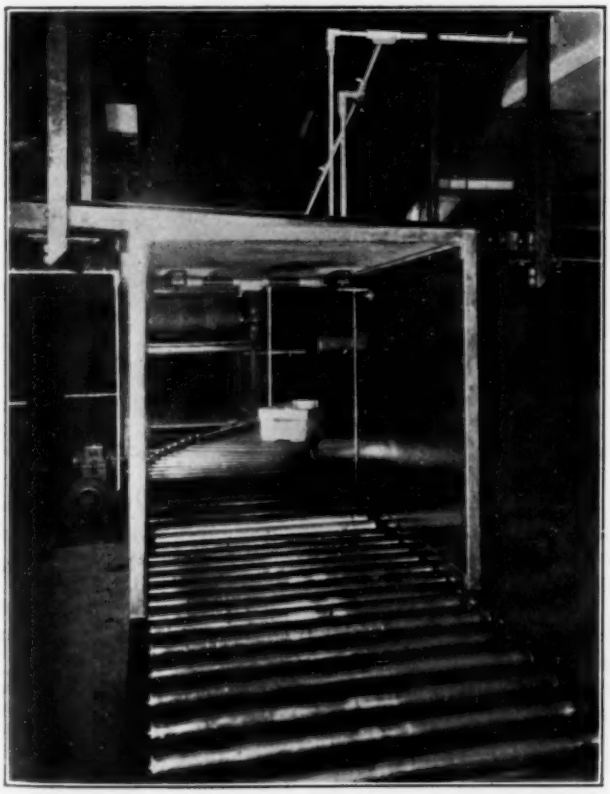


FIG. 15 AUTOMATIC SWITCH SHOWING LIVE ROLLERS AND HOOD



FIG. 17 AUTOMATIC FEEDER BELT AT "Y" INTERSECTION

There is also at the dispatcher's position a microphone and the various controls of an extensive public address system, by which he can transmit information concerning incoming material to the storage floors above and concerning outgoing



FIG. 18 SORTING POSITIONS SHOWING FOOT CONTROL OF SMALL BELTS

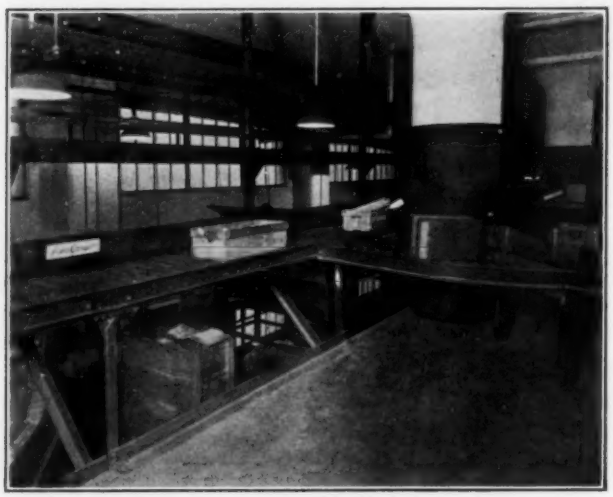


FIG. 19 CHECKERS' POSITIONS SHOWING PARCEL-POST CONVEYOR AND RETURNED EMPTY CONTAINER LINE HUNG FROM CEILING

material to the car-loading positions or the shipping platform.

When the dispatcher receives the orders for apparatus via the pneumatic tube, he places one order in a container, which, when empty, is brought by his position on a belt conveyor controlled by pushbutton.

Containers. These containers are made of wood reinforced by woven wire, and have a small plate of hard rubber on the bottom with two brass spring plates 4 in. apart, lengthwise of the container. (Fig. 10.) These brass springs are connected by wires to the two sides of a telephone jack, which is in a hard-rubber post fastened to the end of the container. When a telephone plug is placed in this jack, a circuit is completed from one brass spring to the other, and in this manner the automatic switching is done.

The plugs are equipped with a colored disk, and as each floor has a color assigned to it, the dispatcher places in the jack a plug with the colored disk of the highest floor nterested in the order. He also places the plugs with colored disks for the remainder of the floors in the bottom of the carrier with the order. Then he presses the button controlling the empty carrier feed



FIG. 20 PARCEL-POST CHECKING AND PACKING OPERATIONS

belt, and the carrier is fed to the upgoing belt, which is traveling at 150 ft. per min. He sets his switches so that the carrier goes directly up to the highest floor interested in the order.

Here the carrier switches off into a live roller conveyor, making a large loop around the floor, and as it passes by the broken package racks, the selectors stationed there examine the order and place in the carrier the apparatus called for, placing the packed stock quantities in their boxes directly behind the carrier with the order number written on them. The selector then removes the first plug and disk and places in the jack the plug and disk for the next interested floor below and lets the carrier go.

The carrier proceeds around the conveyor loop, and by means of the contact points on the bottom works the automatic switch, which diverts it on to a descending belt to the floor below, where it travels around the loop. (Fig. 11.) The packed stock box, because it has not contact points, throws the automatic switch the other way, diverting the box to a descending belt,

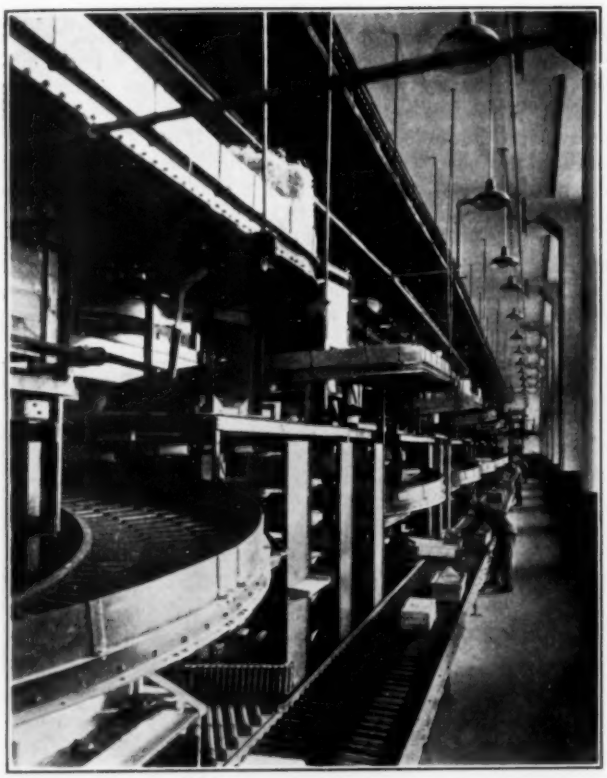


FIG. 21 MISCELLANEOUS PACKING POSITIONS AND SIX STORAGE SPIRALS, MARKING, AND WEIGHING POSITION



FIG. 23 ALLIGATOR SWITCH



FIG. 22 MISCELLANEOUS WEIGHING POSITION AND PUSHER-BAR ELEVATOR

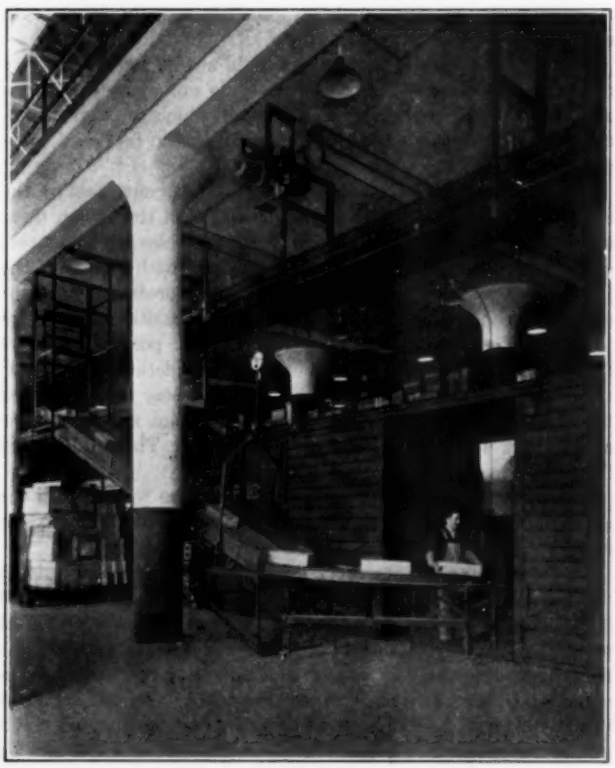


FIG. 24 "LOWERATOR" AND PORTABLE CONVEYOR LOADING CAR ON INSIDE TRACK

going directly down past the dispatcher's position. (Fig. 12.)

The carrier proceeds around each loop on every floor in this manner until the order is filled. Then the last selector removes the last plug, and the carrier travels in the same manner as a packed stock box by the dispatcher's position.

Live Roller Curve. It was necessary to develop a new type of live roller curve which could have its rolls adjusted as to lead, so that the carriers would remain parallel with the conveyor



FIG. 25 SMALL FLAT CAR USED AS BRIDGE

after rounding four curves. This was accomplished by using the live roller principle and a 2-in. belt and snubbing down every 2 ft., so that the belt could take an eighth turn and change direction almost like a rope drive, then slotting the inside frame lengthwise, and by using a clip on the shaft end, the lead can be adjusted within limits. (Fig. 13.)

Gate Sections. The gate sections could not be made of gravity rolls as it is essential that the carriers do not catch up on one another. A belt section was developed which is driven from the live roller section preceding it and which can be raised without shutting off the motor. (Fig. 14.)

Automatic Switch. The automatic switch is controlled by the carrier as described. (Fig. 15.) Just ahead of the switch there are two "hot" rolls connected to opposite sides of a 110-volt circuit. When the carrier passes over them with a plug in the jack, the circuit is completed, and the motor-driven alligator switch responds if it is in the right-hand position and shifts to the left. If it is already in the left-hand position, it stays there. The box, not having means of completing the circuit, throws the switch to the right or compels it to stay there. Mixed trains of boxes and carriers can pass this point and throw the switch back and forth if they are 3 ft. apart. The selectors are instructed to allow 5 ft.

It was necessary for a counting device to be worked into the circuit so that the switch will not be thrown until the box or carrier counting in has counted out on the correct line.

"Y" Section. The conveyor line from the floor above joining the loop on the floor below makes a "Y" section necessary, and if not automatically controlled, would have been a source of trouble. A feeder belt of 4-ft. length was placed in the gravity roller preceding the "Y" section and a floating roll in the down-coming line, so that when a carrier is coming down and depresses the floating roll, it shuts off the motor operating the feeder belt and starts a timed relay, giving the carrier a chance to get on to the loop before the main-line feeder belt is started up again. (Figs. 16 and 17.)

Sorting and Packing. After the carriers and boxes pass the dispatcher, they loop around to the sorters position, where they are mechanically sorted four ways—l. c. l., express, miscellaneous (needing packing), and carload. The sorter does this by pressing a pedal under the box or carrier when it arrives opposite the belt he wishes to sort it on. This pressure elevates two short belts running at right angles between the rollers and carries the box to a belt running at right angles from the main conveyor. (Fig. 18.)

The l. c. l. and express lines take only those packages that are standard packed boxes. They run almost the entire length of the building to the clerks who make out the waybills or express receipts, providing adequate storage for peak loads.

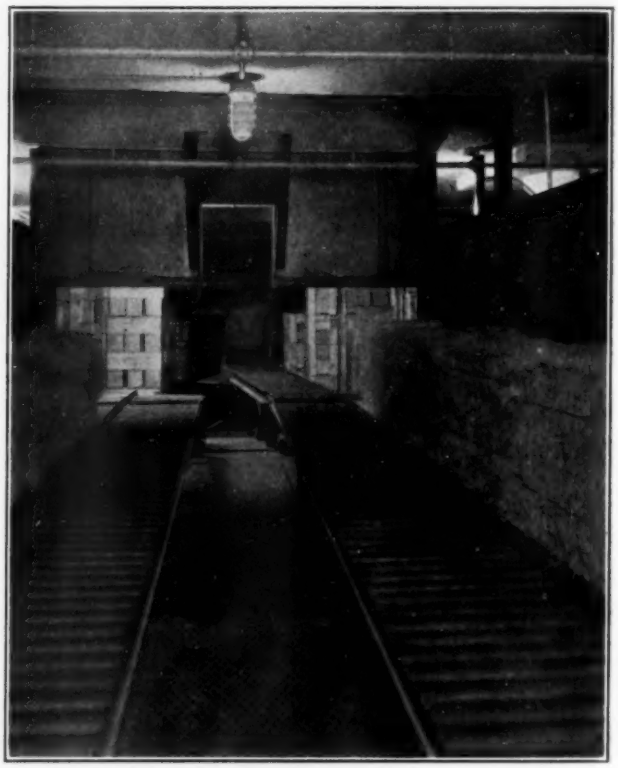


FIG. 26 EXCELSIOR STORAGE BIN

The miscellaneous line takes the containers and the small amount of packed stock boxes to the checkers' positions. (Fig. 19.) Here the checkers place the containers with apparatus going parcel post on a conveyor line going to the parcel-post packing position or transfer the contents from the container into a packing box, which they obtain from a rack conveniently located behind them. (Fig. 20.) The checkers then let the boxes run down a gravity spiral to a packer located on a platform within the spiral and midway between the first and second floor levels. The checker places the empty container on a conveyor line directly above the parcel-post line, which takes the empties back to the dispatcher for reuse.

The packer stuffs the box with excelsior and seals or nails it and lets it continue down the spiral until it arrives on the first floor level, where the spiral empties on a long live roller conveyor. (Fig. 21.) There are six of these spirals all emptying on the same live roller conveyor, where they are marked, weighed, and returned by means of a pusher-bar elevator (Fig. 22) to the second floor, joining the l. c. l. or express conveyors referred

to, and are diverted, as required, by an alligator switch controlled at the scale position. (Fig. 23.)

The boxes, after being accepted by the express clerk, who works along the conveyor line, run down through the second floor and into an express truck trailer stationed in the auto court.

The l. c. l., after passing the waybill clerks, go down through the second floor and out into Building 72 and directly into an l. c. l. car.

The packing boxes going into a car to some distributing house take a fourth sorting line, and the dispatcher directs their course of travel through the remote control of the switches. Only one car is loaded at a time, and this is done by a belt used as a "lowerator," which is lowered by the dispatcher from his position by means of pushbutton control and is recorded on his signal panel by means of lights. (Fig. 24.)

This lowerator delivers the boxes opposite the car door, and when a portable curve section is attached, the boxes run into the car. When the lowerator goes down, its downward movement throws a deflector across the live roller line feeding it, but the actual movement of the belt on the surface of the lowerator is controlled by a floor-operated clutch, which is in the control of the loading gang.

When the dispatcher is sending boxes to a new car position, he announces it to the loading gang through the public address system. He then raises the lowerator he has been using and lowers the one he wants to use. When he presses the button to raise or lower, a loud Klaxon, which is operated on the motor hoist directly above the moving end of the lowerator, warns those in the vicinity of such movement; also the entire bottom of the lowerator that comes in contact with the floor is covered with a hinged plate, which is part of the limit switch, so that if some obstruction were in the way, the limit switch would operate before the weight of the lowerator would come upon it.

In place of bridges across the railroad tracks, small flat cars, 12 ft. by 11 ft. 6 in. with roller bearings, have been installed. (Fig. 25.) These have rings on the four corners and can be lifted out of the way by the crane when cars are shifted, can be rolled along the track to affect convenient crossing points, and can be used to move small loads of material to the dock for water shipment.

The broken-package material selected for the switchboard jobs and sent to the first balcony in Building 72, where the switchboard accumulation racks are, is selected in the same carriers and in the same manner as described and is sorted out on the l. c. l. line and diverted by the waybill clerks to a conveyor taking it to the balcony in Building 72. Here the carriers are unloaded, and they continue on the same conveyor to the dispatcher's position for reuse, joining the other empty container line.

The excelsior-storage bin is suspended from the ceiling of the second floor of Building 71 in the long slot over the general packing line on the first floor. The excelsior is stored on conveyors and is sent to the various packers' positions on the conveyor. (Fig. 26.)

MH-52-7

What Does the Materials-Handling Equipment Manufacturer Need to Know to Make a Successful Installation?

By N. H. PREBLE,[1] DETROIT, MICH.

The answer to the problem of making a successful installation of material-handling equipment is not always simple and, due to varying conditions, is not always the same. In general, however, the following conditions must be examined: (1) Purpose of proposed handling installation. (2) Nature, weight, size, etc., of material or articles to be handled. (3) Capacity required. (4) The path which the material must follow. (5) Details of building or space within which the equipment is to be used. (6) General information as to power available; unusual conditions of temperature, moisture, etc.; erection conditions; and the like. The paper outlines in detail these various items, with a view to assisting the buyer.

THE question as to what does the materials-handling manufacturer need to know to make a successful installation is not easy to answer in any simple terms. One is tempted to say, merely, that he should know everything which can in any way affect the selection of equipment, its design, manufacture, installation, operation, and maintenance. But that, after all, is no answer, as many, if not most, prospective users cannot recognize just what will affect these various points. Furthermore, the user will frequently have only a vague idea of how to get started in the collection of the required information, and not being fully aware of what type of equipment may be available, will be unable to make a proper selection.

In many large corporations, on the other hand, the plant-engineering department will include a division or group specifically charged with the solution of handling problems. This group may have sufficient knowledge and experience to select equipment, arrange all details of its design and installation, and issue complete specifications and drawings, all without reference to or advice from the handling manufacturer. However, even in a case of this kind, it may be well worth while for the user to lay his whole problem before the manufacturer, who frequently, with his more general experience in plants of all sorts, can make valuable suggestions. The manufacturer is also more familiar with new developments in design or methods. From the standpoint of the manufacturer, it is well to check very carefully into the specifications and drawings which may be issued in a case of this sort, as numerous instances have arisen where some detail of construction or design has been overlooked, also where slight changes or possibly major changes would materially improve the operating results of the selected apparatus. The author has in mind an instance which actually occurred, where a user submitted complete drawings worked out in great detail, involving the handling of certain articles on an existing truck. It so happened that the manufacturer to whom these drawings were submitted was acquainted with the details of the problem and the design of the truck, and found immediately that the conveyors were so laid out that they would not operate properly with the trucks which must be used. This, in spite of the fact that the drawings were supposed to be correct, and had been checked and issued as working drawings. Incidents of this sort are not infrequent, and it behooves the manufacturer to be very careful in going over such drawings and specifications as may be submitted to him.

In most plants, however, no such complete drawings and specifications can be made up, as the engineering department is not properly equipped to do this type of work. In order to make our story complete, we will therefore consider this type of user, who has no organized materials-handling department and only a limited knowledge of the means available for the solution of his handling problems. He may perhaps not even recognize that a handling problem exists, and will only recognize it after a suggestion has been made by some outside party.

In preparing our data, the first thing we should do is to examine the purpose or reason for the contemplated equipment installation. In order to clarify this discussion, let us divide handling equipment into classes according to purpose. We find in general, three main divisions:

(1) *Transportation.* Where the purpose is merely to move material from one point to another, vertically, horizontally, or on an incline.

(2) *Assembly.* Where an article is carried, continuously or intermittently, from one work station to another, various parts being added or operations performed while in transit, the article usually remaining on the equipment throughout.

(3) *Processing.* Where some process is performed, such as painting, drying, baking, heat treating, or the like.

The combination of any two or all three divisions will occasionally be required, but practically all handling problems will be found, on examination, to fall in one or more of these main divisions, and a recognition of these main divisions will frequently assist in the analysis of the problem to be solved.

It will immediately be apparent that within each division, certain types of equipment will predominate, but the final selection will depend on a thorough examination of the individual and peculiar requirements in each case, in addition to a mere examination of the purpose to be accomplished. For instance, in the transportation of packages, using that term to distinguish from bulk material, the truck or trailer will, in general, be selected, if the path to be traveled is to vary and is to cover a large area. If however, the area is limited, certain conditions may make a crane more suitable, while if the path is fixed a conveyor will frequently be the final selection.

Bulk handling equipment, as the bucket elevator, the belt, or screw conveyor, will almost invariably fall in the first classification of transportation, although some process such as drying might be included, but it cannot be assumed that in any particular instance the best apparatus for the transporation of bulk material is necessarily of this particular type.

The user must therefore start out without bias, and rather than assume that he needs a certain type of equipment, should state the purpose for which this equipment is to be used, fully and

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Presented at the Third National Materials Handling Meeting, Chicago, Ill., March 5 to 7, 1939, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

clearly, and ask for recommendations or bids. In equipment for simple transportation the explanation of the purpose is relatively easy, but it should be remembered that it is possible that in addition to transportation it is desirable to have a certain amount of storage. For instance, on some conveyors for transportation of material from one point to another, particularly in the case of the overhead power-driven trolley conveyor, it is desired to use the conveyor as a storage bank, and if such a requirement is desirable, that fact should be clearly stated.

Where assembly operations are involved, a carefully detailed operation sheet must be made out, covering all operations to be performed, together with a time study of each operation. It will also be necessary to examine the means for bringing the stock to the assembly line and the storage space required for such stock alongside of the line. This work should be taken care of by the user, either directly or through the use of some consultant service. Occasionally the equipment manufacturer is in a position to assist in the accumulation of this information, but the responsibility really devolves upon the user, who is more familiar with his operations and conditions than the manufacturer can be. These studies lead to a final determination of the number of work stations required, time or space for each, and finally the spacing of the work, the length of the line, and the speed required.

When the purpose for which the equipment is to be used comes under the third classification of processing, the time element must again be carefully determined and stated, also all possible information as to the details of the process, the temperatures involved, any special conditions as to high moisture content of the air surrounding the equipment, acid fumes, and the like.

Having determined in complete detail the purpose to be met, one must next turn to an examination of the material to be handled. For bulk material, this must include the nature of the material, its weight, and condition. A statement of what the material is would ordinarily be sufficient explanation of the nature although in the case of some special compounds further details might be given. Weight should be expressed in pounds per cubic foot, with a further statement in some cases as to whether this is dry weight or total weight, including the actual entrained moisture. If the material is any special condition, as wet, sticky, hot, or frozen, these facts should be noted, and where lumps exist the size of the largest and smallest pieces should be given.

If the material to be handled is an article or package, full dimensions and weights of each piece should be furnished. Where the shape is at all complicated, such dimensions should be accompanied by a sketch or blueprint showing full details. The weight of each piece and the material from which it is made should be noted, together with any pertinent comments as to special care required to prevent breakage, marring, scratching, spilling, or the like. This last item is quite important, at times determining the design of equipment, and it is sometimes impossible for the equipment manufacturer to determine how much care must be taken in handling. Sheet-metal parts for instance are frequently finished with a very high finish, in which case scratching of the piece would cause considerable extra work. In other instances, it is not important. The type of finish to be applied might therefore materially affect the selection or design of handling equipment.

Having covered the purpose of the proposed installation and the material in full detail, one should next take up the question of the capacity desired. For bulk material a simple statement as to the tonnage required to be moved per hour may suffice. If, however, the volume or tonnage varies greatly from time to time, maximum and minimum should be noted, and if the equipment is to be used only intermittently, the length of time within which it is desired to move a given quantity must be stated. These conditions of varying capacity and intermittent use may determine the size of the equipment, and in some cases the desirability or economy of a variable-speed driving mechanism. For instance, if one is considering a portable conveyor for unloading a car of coal, it would be possible to use a very small machine which would take a considerable time to handle a full car. However, it may be necessary that the car be unloaded in considerably less time, which in this case would involve the use of a larger machine. This simple illustration shows the importance of knowing the time interval where the equipment is to be used intermittently.

For the transportation of articles or packages the capacity will be determined by the number of pieces of each kind or size which must be moved in a given length of time but one must also know what the sequence of the various pieces is to be, where more than one size or type is to be handled; that is, whether one is to move a large batch of one particular kind, and then the other sizes, or whether these are to be mixed up in the handling. One should also know whether they are moved to an assembly operation or conveyor requiring synchronized speed and the sequence or rotation of the various parts properly to feed such a line.

For assembly or processing operation, this information should be further amplified by details of how closely the articles may be spaced together; that is, the maximum room required around the article for the operations involved. If any special or unusual conditions exist which would affect the loading or unloading of the equipment, no matter what the purpose is, such conditions should be fully explained. It is sometims necessary to design equipment which will unload or load automatically from some other equipment. In other instances, the loading will take place at more than one spot or, on the other hand, may be entirely confined to a limited space, all of which may have a considerable effect upon the equipment.

The next question to examine is the path or paths through which the material must be moved, and until this is fully understood one cannot even start to determine the type of equipment to be used. The best way, and probably the only clear way for, the user to answer this question if the path is at all involved is by means of a layout sketch or drawing, giving a fully detailed plan of the entire area involved, together with full and complete elevations and cross-sections. Alternate paths should be shown, together with notations of obstructions existing, which cannot be removed, or on the contrary, which can be removed if necessary. Such drawings may not always be necessary, but will be valuable, except in the most simple instances, in giving a clear picture. Usually, if such drawings and sketches and elevations are not submitted, it will be necessary for the manufacturer to make an actual inspection of the plant, which may involve considerable additional expense and delay.

With all of this information at hand, an analysis can be started to determine the most suitable type of equipment to meet the particular problem. However, some building conditions may exist which might influence this choice, and as one must have full details of the building or area within which the equipment is to be installed before one can formulate a bid, it is well for the user to supply this information at the same time as that already discussed. This should include full detail in regard to the construction and dimensions of the building within which the equipment is to be used or, if outside, the nature of the ground over which it is to operate. Building information must include all details of the obstructions, such as steam pipes, sprinklers, light fixtures, conduits, ducts, and the like, which cannot be removed. Type of floor constructions should be noted, and if any equipment may possibly be hung from building steel, detail of that steelwork should be shown, with notations as to whether it may be drilled for the attachment of hangers or other structure. In concrete buildings, thickness of the floor should be shown, together with the type and location of ceiling inserts if any exist. Where open-

ings are to be cut through the floors or walls, it should be definitely understood whether the user contemplates doing this work, together with the patching and housing of any such openings himself, or whether he expects this to be done by the equipment manufacturer.

At the same time that the building details are given certain miscellaneous items should be covered. Under this heading come electric current characteristics; a notation as to special atmospheric conditions, if any such exist, etc.; if bids are desired, any unusual condition surrounding the installation of equipment should be explained fully, especially the necessity for the use of union labor, for working overtime, or possible interference with the user's production. If the user has standardized on the use of certain types of devices, such as grease fittings, speed reducers, variable speed transmissions, and the like, such special preferences should be clearly noted. In some instances the user, due to already having in a considerable amount of equipment, would prefer certain very distinct types or makes, and where such preferences exist, this should be explained for the guidance of the manufacturer.

This, then, covers the questions of general physical requirements in a manner which will usually be found sufficiently complete. Assuming the data to have been properly collected and presented, the manufacturer will be able to submit proper recommendations, prepare drawings or designs, and offer bids for the installation.

We must not, however, neglect another phase of the question, and that is the economic side. No material-handling installation, however successful it may be mechanically, can be considered a true success unless it is justified from the economic standpoint; in other words, unless it pays its own way. Usually the question will arise as to how quickly must the investment necessary to make the installation be returned in savings in order to make it worth while to go ahead with the installation. This question cannot be answered without considering the type of installation or equipment under consideration, for the rate of returns which must be expected will vary with different types of equipment. In general, if the equipment is almost certain to remain in use for a long period of time, if its maintenance or actual physical depreciation and its probable obsolesence are low, the rate of return can be considerably below that of some other type of apparatus whose period of usefulness is somewhat limited and whose maintenance and depreciation are high. If the industry or plant into which the equipment is to be placed is in a state of flux, the rate of return must be high. This consideration has influenced the automotive industry, in general, to make a rather blanket rule that no handling equipment shall be installed unless it will return the entire investment within a period of twelve months or less, and in view of the fact that the plants are so frequently rearranged, this ruling is in all probability justified. In other industries and for other types of equipment a longer period would be economically sound.

There is, however, some danger of looking at this question purely from the standpoint of labor saving, perhaps because that is the easiest thing to determine in definite figures. Very frequently, however, there will be other considerations which will be of equal importance, or sometimes of even greater importance. It is conceivable that the total production of a plant can be materially increased; that a very serious congestion in aisles, driveways, or elevators could be reduced sufficiently to warrant a considerable expenditure. In other instances, excessive breakage or damaging of goods might, without at the same time effecting a reduction in labor costs, be a sufficient factor to warrant an installation which in itself would not make any saving in labor costs. Conditions of this sort are not by any means unusual.

One must therefore consider these ends or means in addition to the physical factors which have been discussed. It is found very difficult, however, to lay down hard and fast rules for the gathering of information along these lines. Probably the only thing that can be done is to have a discussion with the representatives of the equipment manufacturers, who will be able in most instances, and always glad, to assist in pointing out what can or what cannot be accomplished to overcome the difficulties or conditions which the user has to face. It is entirely possible that such a discussion will disclose the fact that certain types of equipment which have been recommended from the physical standpoint might be economically unsound, due to excessive expense or some other condition, and the recommendation might therefore be changed to some more inexpensive apparatus which, while not making as great a saving as the other type, would be more certain to pay its way.

MH-52-8

Materials Handling in the Plant of the Goodyear Tire and Rubber Company

By C. C. STUBER,[1] AKRON, OHIO

In the plant described, 964 people are kept busy transporting an average of 1,863,269 lb. of material in process of manufacture over a floor space of 6,443,419 sq. ft. by the use of 17,000 electric power trucks, industrial hand trucks, and platform skids. This equipment would make a train 19 miles long. There are 81 elevators and 29,654 ft. of conveyors. The industrial trucks are under centralized control.

INDUSTRIAL transportation, as applied to our organization, means the one best way of transporting material in the shortest possible time with the least expenditure of money and energy, so that the part played by transportation, in the final cost of the finished product, is reduced to a minimum.

As we know, there has been misconception in the minds of some as to just what is meant by inter- and intra-transportation and what it amounts to in our factory. Such confusion may be entertained when consideration is given to our problem of unloading 77 freight car loads of raw material daily. This requires a careful study of suitable transportation routes. From the staggering number of 1214 transportation routes in the beginning, we have been able to reduce the number to 415 routes.

A personnel of 964 can transport an aggregate weight of 1,863,269 lb. over a floor space of 6,443,419 sq. ft. by the use of 17,000 electric power trucks, industrial hand trucks, and platform skids. If such equipment could be coupled together, it would complete a train more than 19 miles in length, capable of transporting 34,000,000 lb. of material, occupying a floor space of 306,000 sq. ft.

There are 81 elevators distributing truck loads among the various floors.

Revolving independently are some 29,654 ft. of electric and gravity conveyors which are mounted on especially strong and rugged frames. From their remote controls, they can be governed to facilitate and expedite an even flow of material to the various machines along their path. The ease with which material is placed on or taken off the conveyor by the operators is gratifying to note. The conveyors are equipped with safety features.

Such a tremendous capital investment must be economically and efficiently handled, and, in so far as industrial transportation cannot be eliminated, it therefore becomes necessary and a part of the manufacturing process. We know that transportation does add to the value of the product (which is contrary to previous statements), as care must be taken in handling the various elements which go to make up our products. To prevent any of the elements from becoming contaminated by foreign substances while en route may protect and preserve the quality of our product.

By analyzing our transportation problems, our scientific investigations disclosed much lost time and wasted motion among our suppliers, the confusion of transportation deliveries between various departments, and the multiplicity of various different types and styles of truck equipment. We then realized its imperfections. When we realize the amount of internal transportation and why it is necessary to continue to carry back and forth the equivalent of 16 times the weight, for such is the actual handling of 29,812,304 lb. before the finished product is completed at a weight of 1,863,269 lb., is not the total rather staggering?

Fabulous sums have been expended for installation of mechanical or gravity conveyors which were substituted for trucking. Such installations were made on the prominent routes, where the fleets of the greatest number of trucks were operating. When such routes were conveyorized, it not only eliminated the trucking operations, but allowed additional space for production which formerly was occupied by trucks.

The extent to which a transportation system may be extended by an overenthusiastic manager may not only result in a rising cost, through the expense of operating, but may slow up actual production.

For the purpose of administration and accounting, the functions of our transportation organization are divided into the following units:

A Transportation of raw material from our unloading docks to our various warerooms and then to preparatory divisions.

B Transportation of all prepared stock to their respective cushions ahead of assembling divisions.

C Transportation of articles while in the process of being manufactured and manufactured articles to finished-product storerooms.

D Transportation of finished articles from finished-product storerooms to the various shipping departments.

E Transportation of material by electric power trucks.

F Industrial electric-truck batteries-charging division.

Each division is in charge of a foreman and is subdivided into sections controlled by a head supervisor. Each section is subdivided into as many parts as are necessary to render efficient service for the transporting of material, and each of these subdivisions has a supervisor in charge.

Items for consideration are:

A Standard equipment.
B Aisleways.
C Return loads.
D Routing of deliveries in cycles, or one way traffic.

The supervisors are trained for their duties and rights within the organization and are taught all the intricacies of industrial receiving and shipping, such as careful planning and routing, for the transportation man must have a technical knowledge, not only of his position, but also of the material he is handling. This can be obtained only by a systematic study of all the factors which enter into the service of transportation as well as those directly affecting department shipping and receiving.

All transportation suppliers' wage earnings are computed on a piecework basis. All piecework operations include the following:

When material is loaded upon equipment for transporting or stowed in any of the raw-material or finished-product storerooms, the material in question will be segregated according to quality, size, and type and placed in the proper location.

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[1] General Foreman, Goodyear Tire and Rubber Co.

Contributed by the Materials Handling Division and presented at the Akron Meeting, Akron, Ohio, October 21 to 23, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

The marking on the various articles will be facing one way when in storage or on equipment, so that the description on articles will be accessible for any one to read. When a supplier is dispatched for material, he will see that just the amount, size, and type, as requested on order, are loaded.

Material, whether raw, in the process of being manufactured, or in the finished product line, must be loaded upon, as well as removed from, platform skid, truck, or conveyor in a satisfactory manner.

In no case shall a supplier push a load of material off a platform skid, truck, or conveyor, as in all cases where this practice is tolerated it may result in considerable damage.

These items are carefully checked to avoid unnecessary repiling of material resulting from slovenly work on the part of the supplier, as repiling causes an increase in the unit cost of the department to which material is being delivered.

When material is delivered to a department for use of the department's craftsmen, the supplier distributes his load in such a way that all craftsmen will be kept busy and so that there will be no lost time in waiting for or going any distance for raw material. The supplier's incentive, of course, is that, operating on piecework himself, the greater the amount of material the craftsmen consume and the smaller the possibility of a delay in the craftsmen's duties, aided by his own elimination of delays in operation, the greater will be his earnings. This is so important and has such a far-reaching effect upon the output of the factory, by keeping the craftsmen contented and maintaining an even and regular distribution of material, that such distribution is not left entirely to the supplier, but is very carefully watched by the transportation supervision cooperating with the production departments. Delays cause a loss in production that not only occasions a loss to the company but also leads to labor dissatisfaction.

Accounting Control

The cost of transportation service is charged directly to the production division from which material is being transported.

Industrial transportation equipment is divided into 44 classes, and a code number is set up for each class. There are 13 classes or codes for electric power trucks, 4 classes for batteries, 22 classes for industrial trucks, and 5 classes for platform skids. All repairs, lubrication, and depreciation are charged directly against a class or code. Industrial transportation equipment is allocated according to production departments, and truck maintenance is charged to the production division according to such allocation.

Delivery Control

A daily or weekly schedule, listing quantity and description of material, is the authority for delivering of material.

Centralization and Control of Equipment

Industrial-truck equipment throughout the factory is controlled and operated under one centralized authority. Without such unity of neutral centralization, each production department would maintain its own trucks and they would become a secondary issue, their real importance not being recognized. While one department would be struggling along with inadequate equipment, due to a sudden increase in production or a breakdown in truck equipment, another department might have a surplus of such service due to a decrease in production or unexpected layoffs. In this way both departments would be operating at a loss. Still other departments would try to obtain more trucks than their quota, so as to have a surplus for a safety margin.

There is also a duplication of effort through the return of an empty truck after making a delivery. Centralized control, whose record depends absolutely upon quality of service and minimum of expense, will route deliveries so as to have a return load at all times. This also relieves congestion.

Such centralization of unit control was established to study and eliminate all waste effort, confusion, and friction between production departments relative to industrial-truck equipment. All electric and hand trucks are numbered, prefixed with a code letter. All truck equipment is divided into 44 classes, according to size and type. Electric trucks are classified in 13 codes, hand trucks in 22 codes, platform skids in 5 codes, and electric batteries in 4 codes. While the allocation of trucks is set up for each of the various production departments, according to their production requirements, the allocation may be changed from time to time, either increasing or decreasing the number in the fleet.

Standardization of Industrial Transportation Equipment

Until recently the value of engineering service was not recognized in regard to industrial transportation equipment. In the past each department maintained its own idea of certain types and styles of trucks to perform the operations pertaining to its production, with the result that when a production department was discontinued or certain operations were eliminated in the process of manufacturing certain articles, such equipment became obsolete. The salvaging of this equipment, entirely or in part, gave the management the idea to study the needs of the plant's production as a whole and then design a type of truck chassis that would be interchangeable throughout the factory.

A standard type of running gear or chassis was designed with the utmost flexibility in steering and turning through narrow aisles and around sharp corners. This truck chassis could easily be equipped with various types of racks or bodies best suited to the needs of the different departments, and if production department or operation was discontinued, these superstructures could easily be removed at a small cost. The result of this investigation is that, instead of the multiplicity of sizes and types of trucks formerly in use—that is, from a variety of 49 types of one line of trucks—there now are but four types of truck chassis, with a number of interchangeable parts, which answer all the requirements of the original 49 types.

All industrial four-wheel trucks are equipped with standard couplers. Such flexibility enables operating the electric tractors in any industrial truck cycle.

Where material is consumed slowly, the platform-skid method of transportation is adopted. In the installation of the platform-skid method a standard height is maintained in order to obtain a flexible service unit, so that the transporting can be performed by either hand or electric lift truck. When it is necessary to move platform skids a short distance only, it is entirely satisfactory, as well as efficient and economical, to equip such platform skids with casters or wheels, to eliminate the necessity of waiting for the arrival of a supplier with a transveyor. The craftsman can then move the platform-skid load whenever necessary without the loss of time.

It has been found that properly selected electric trucks, powerful, compact, and the minimum in weight, are well adapted for certain types of transportation service, and a fleet of 73 electric power trucks is helping to keep down the cost of transportation. All electric-truck battery compartments are so designed and built that they will receive any style of battery that we employ. Such interchangeability of batteries allows the service of each electric truck for the 24 hours.

Inspection and Lubrication

Trucks are first inspected for condition before being lubricated; that is, all bolts are tightened, and those small miscel-

laneous repairs which are necessary to place a truck in first-class condition are made. A pressure lubricating method is standard equipment. Inasmuch as trucks are always equipped with some sort of a lubricating system, such as greasecups, oilwells, oilcups, etc., which in time become clogged with dirt and grease which has hardened due to certain conditions existing in the factory, not only has the pressure system of lubrication proved considerably more effective, but it is less expensive than the former method.

When lubrication is completed, the truck is given a thorough cleaning. All foreign substance is removed from casters, running wheels, and deck. All trucks are painted yearly.

A card index is maintained, recording the truck number, the number of the production department to which the truck was allotted, the date the truck was lubricated, and the date the truck was repaired. Such information affords an opportunity to nvestigate the reason why any particular piece of equipment must be repeatedly oiled or repaired.

Maintenance

Observation of industrial transportation equipment under actual service, relative to wearing qualities, length of service, and ease of operation, discloses many mechanical defects in the design.

Considerable experimental work has been done to determine the right type of wheel construction, especially the best width, as floor maintenance seems to be exceedingly high. The results of this investigation are found in the recent development of a satisfactory tire wheel for the industrial truck wheels and casters. It is gratifying to note the ease of motion while the truck is in operation and the absence of truck vibration.

A centralized truck-repair department has decreased the truck maintenance cost considerably, for as soon as a defect is noticed in a truck, the truck is immediately placed in the repair department for repairing or overhauling.

What has been accomplished may be seen from the evolution of transporting material by hand to conveyor. The progressive steps are:

A Hand.
B Two-wheel baggage trucks.
C Four-wheel flat-deck trucks.
D Hand lift truck and platform skids.
E Electric tractor and four-wheel flat-deck trucks.
F Electric transveyor and platform skids.
G Rearrangement of machines.
H Mechanical power conveyors.
I Force of gravity.
J Linking together machines into one unit.

MH-52-9

Symposium on the Economics of Delivery Service

Commercial Operation of Electric Trucks and Trailers Compared With Gasoline-Operated Vehicles

A recent treatise on the development of electric service in the smaller towns and rural districts contains the following significant statement: "The ability to ship by truck or rail from and to any point and available power supply at almost any place have made it possible for American industry to remove and remold itself at will."

These papers cover gasoline and electric vehicles and discuss the application of motor trucks operated over public highways to the service of industrial plants. The economic place of the truck is approached from two angles:

1 Its function in promoting (a) the flow of raw and semifinished material into the factory or plant; (b) the movement between plants under a single management or from any of these plants to the warehouses or branches; and (c) the final physical distribution to customers or consumers.

2 The ownership of the trucks engaged in the productive process as (a) by the industrial plant itself or (b) by outside specialists working as contract or common carriers. Operation and maintenance of "owned" trucks may be assigned to various plant departments or even to a subsidiary company. The conditions affecting the preferred type of control or organization are considered.

The several authors also take up at some length the growth of motor express and freight companies, especially emphasizing their relation to the industrial plants, particularly of the type that is manufacturing goods that are shipped in small lots and sold through outlets dealing directly with the general public.

Economic Aspects of Gasoline-Operated Commercial Vehicles

By R. E. PLIMPTON,[1] CHICAGO, ILL.

INTERNAL transportation, or the materials-handling facilities entirely within industrial plants, has been the subject of many comprehensive papers presented before the Materials Handling Division. These have covered the control, application, and design of industrial trucks and tractors confined to the buildings or the private roadways within manufacturing establishments. Little attention has been given, it appears, to an equally important matter, namely, the general economics of the highway motor vehicle engaged in one or more phases of the process of production. Hence the aim of this paper is to discuss the contribution that has been made by the motor truck and the public highway, wherever they may be used in the service of manufacturing establishments.

By way of introduction let this fact be emphasized: details of construction and methods of maintenance will be improved as time goes on, but the pressing problem is to get the best use from the well-developed truck equipment now on the market and from the fairly well-organized haulage companies.

The field of application of the truck and its utility to the industrial plant is steadily increasing. In recent years higher truck road speed has been a powerful influence in decreasing plant inventories, with attendant lower capital charges for material in process of production. Highway developments are permitting the elimination of bottle necks caused by congested freight terminals in many of the large metropolitan sections, while in sparsely settled parts of the country the highway furnishes a more direct route than available railroad facilities. These better roads have helped sizable towns to grow up miles away from any railroad. Indiana is said to have 686 towns lacking steam-railroad service. Of this number 166 possess small industries. These receive raw material and ship goods entirely by truck, and largely by vehicles of the common-carrier variety.

The influence of the highway on manufacturing establishments has been so obvious that sometimes its importance passes almost unnoticed. But studies made in the last year or so have given us a national perspective on the problem. The report of the Committee on Recent Economic Changes[2] refers in several places to the "prevailing tendency toward geographical decentralizing of production." Manufacturing has moved to the country, it is asserted.

"The ability to ship by truck or rail from and to any point and available power supply at almost any place have made it possible for American industry to remove and remold itself at will." This quotation[3] from a discussion of the increasing use of electricity in the smaller towns and rural sections is supplemented by a statement that the construction of highways and the increasing use of motor trucks have served to equalize plant marketing conditions between large cities and small communities.

That industry is taking full advantage of the highways in "removing and remolding itself," is brought out in another investigation.[4] A meat packer would supply a local market readily accessible by truck. Dealers within an 80-mile radius are served with crackers and cookies not more than 24 hours old. The tremendous expense of trucking in metropolitan centers is elimi-

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[1] Associate Editor, *Bus Transportation.*

Contributed by the Materials Handling Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

[2] "Recent Economic Changes in the United States," published by McGraw-Hill Book Co., Inc., New York.

[3] "America's New Frontier," Middle West Utilities Company, Chicago.

[4] "Industrial Development in the United States and Canada." Report of Cooperative Survey by Civic Development Committee of National Electric Light Association and Policyholders Service Bureau of Metropolitan Life Insurance Company.

nated. These are some of the reasons for new locations of plants or branches given in the Metropolitan Life report. Nearness to markets is the reason advanced most frequently for changes by the sixteen thousand plants from which information was received. Better shipping facilities, especially trucking in New York State, lower trucking costs in Rhode Island, and excellent auto freight service in Ohio, were cited as important advantages in moving either to the outskirts of the larger cities or to more isolated smaller places.

The highway also had its place in new locations selected because of nearness to raw materials, the Metropolitan Life survey indicates. A creamery in Texas is quoted: "We run trucks and pick up all our cream, and we wanted to be near the supply of production." A manufacturer of orange products shifted from one city to another in the same state to be "nearer the center

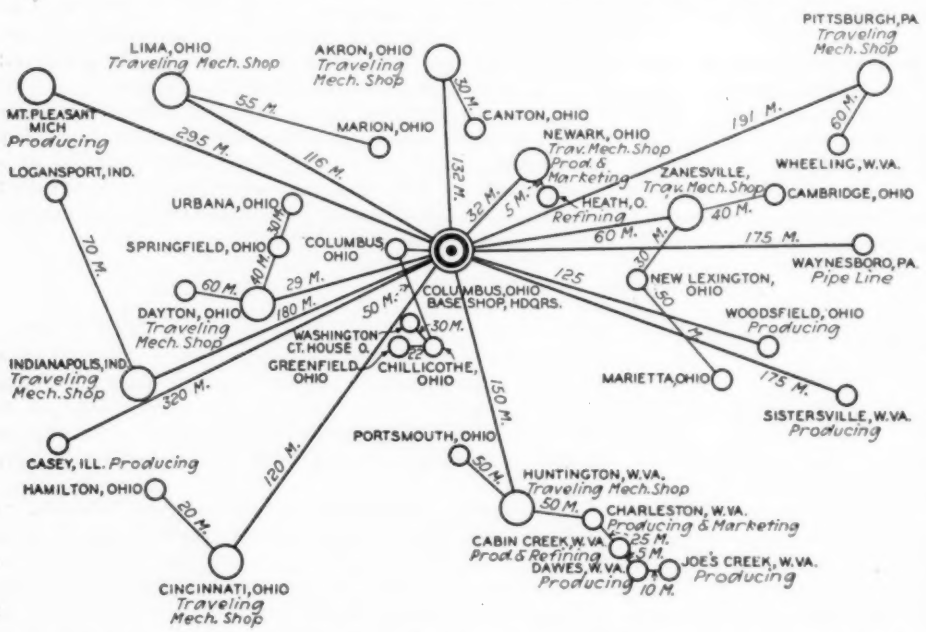


FIG. 1 ROUTES OF CENTRAL DIVISION OF MOTOR TRANSPORT DEPARTMENT OF THE PURE OIL COMPANY WHICH SERVES PRODUCING, REFINING, AND MARKETING IN THE MAINTENANCE OF AUTOMOTIVE EQUIPMENT

of the ton-mile haul on the oranges which we draw from the packing houses throughout southwestern California." One reason for the site chosen by a paper mill locating in Washington was a large number of small stands of white fir and hemlock that could be reached by short auto haul.

ORGANIZATION AND CONTROL

The same acumen displayed in selecting plant location should be used in the truck operation. Who should have the responsibility for the highway vehicles? Should each department using trucks regularly control the operation of certain assigned units, while other parts of the plant having only occasional need for truck service must beg or borrow the trucks ordinarily used elsewhere? To avoid lost motion, to cut down empty or only partly loaded mileage, to keep down the investment and equipment by using the smallest number of units possible, to have one boss rather than half a dozen for the drivers and maintenance force—for these and other reasons there should be a centralized and responsible authority in control of all the truck work. It is necessary to stress the point because most industrial plants, and other users of trucks for that matter, operate their vehicles in the most unorganized and casual manner. Just what this authority is, and the place it has in the main corporate organization, will depend on the use made of the trucks and on whether they are owned by the corporation itself or by some form of commercial carrier.

Unless there is an expert abreast of the subject all the time, how is the purchasing department to know whether incoming material should be taken over at the vendor's plant or whether a price that may be quoted by the vendor for delivery at the purchaser's plant is more advantageous? If delivery is accepted at the vendor's plant, then can the moving be done best by the buyer's own trucks or should the service be purchased from a haulage company? These are problems that are encountered whenever raw and semi-finished materials are to be moved.

Unless such an expert is available, how is the production department to know the best method for moving goods in process from one plant to another? The plants may be a few miles apart in the same city or 75 or 100 miles, and in different towns. The situation may call for use of the corporation's trucks, for the services of a drayage company, or for the use of a motor express or freight company operating on regular schedule. But certainly it needs competent attention

Unless expert advice is available, how is the sales department to know when the highway should be used, and what form of truck movement (owned or hired) is the most economical? Economy here must be judged of course not only by the mere saving of dollars and cents, but by the time saved. There are many other advantages that may be gained in the saving of expense for crating or boxing, and in the good-will that prompt and dignified service may create with the public as well as with customers. All this would be important if the goods were shipped f.o.b. to the plant, but a direct saving would be possible if the selling price included delivery at the customer's premises, as often happens in these days of mass distribution.

Unless expert advice is available, can the accounting department allocate the truck expense among departments? Certainly one of the main functions of the centralized authority here advocated would be to keep adequate cost and performance statistics, not only of the owned vehicles but also of outside trucks. It should also be responsible for carrying out and devising a practical scheme so that the truck expense can be distributed in proportion to the service used by stores, production, sales, or other departments, or by the customers, if the charge is passed on to them.

SUBSIDIARY COMPANY

Let us now consider more definitely the authority that should be made responsible for the trucking activities. A wholly owned subsidiary formed to specialize in trucking and allied activities in many respects offers a clean-cut solution to the problem. The separate company, however, must be dealt with as a corporate entity and required to stand on its own feet. That is, in its function of giving or perhaps buying truck service, the

subsidiary should pay for all it gets from the parent and related companies and charge for whatever work it does for them. This scheme can be more easily carried out if the trucking subsidiary has offices, staffs, and storage and repair facilities apart from those of the manufacturing establishment. The function of such a separate company is primarily to handle work for one customer, but if the customer's demands are irregular with occasional peaks or heavy demand, it may be desirable to hire outside trucks. The use of rented trucks has been advocated in order to try them out on new work and thus determine the right size and number to be purchased. This practice would not be required in establishments that have expert transportation advisers, of course.

A few of the larger corporations using trucks have seen the necessity of a motor-transport department more or less on a par with sales, manufacturing, and other main divisions, reporting directly to the president of the company. This implies usually that the trucks are a large item in the total operating expense and also that they are working for many different departments. They may be widely scattered, as with the integrated type of petroleum companies which own everything from oil wells to roadside filling stations. When all phases of the process of production and distribution are concentrated in a fairly small area, the motor-transport activities may be organized as shown in Fig. 1.[5] This is merely one division of the Pure Oil Company, to which are assigned 250 trucks and 50 passenger automobiles. The set-up would differ slightly in the producing fields of Texas, or in New York and nearby states, where marketing is the chief activity of this company and of its truck equipment.

Ordinarily the truck work will be under some such department as production, traffic, or sales. The White Motor Company, which prides itself on handling its truck equipment as efficiently as any of its customers would, has a city transportation section to pick up goods at local vendors and freight stations. The foreman of this city transportation section reports to a material supervisor, in charge of the storerooms and materials-handling facilities inside the plant, and the supervisor in turn reports to the works manager, so that the truck operation is essentially under the production department. It is said that this centralization of authority has enabled the company to cut down the number of trucks about one-third and still give good service to the various departments.

In the divisions of the Chrysler Corporation, where the movement is almost 100 per cent between factories in various parts of Detroit, the highway truck work comes under the traffic department. The Chrysler Corporation organization includes what is known as an inter-plant transportation department, headed by a superintendent who reports to the director of traffic. The Dodge Brothers and Plymouth plant trucks are likewise operated under the supervision of the traffic-department heads.

Just why the truck work should be assigned in one plant to the production department and in another to the traffic department is sometimes hard to understand. The latter is the authority on rail transportation, and is usually in a good position to apply sound principles of operation and to make a selection as between road or rail if either can be used—this provided it has kept abreast of developments in motor transportation. But a competent staff in the production department is in charge of the internal industrial trucks, and if the volume of work they handle is large compared to that required of the highway vehicles, it is undoubtedly good policy to give this staff the complete authority.

[5] Furnished through the courtesy of Leo Huff, Manager Motor Transport Department, Pure Oil Company, Chicago.

The sales department has the best claim to the control of trucks when they move the product to widely scattered retail sources or dealers. With some petroleum companies perhaps 80 per cent of the trucks are operated for the marketing or sales division of the business. The sales department or its local manager has direct control of the drivers, lays out their routes, and supervises their sales and collection activities. A motor-transport section of the sales department is concerned with the selection of truck equipment, design and construction of auxiliary devices, and with provisions for storage and repairs. The motor-transport section may have a measure of authority over the drivers as regards proper handling of the equipment, but this is likely to be more or less advisory and exercised only through cooperation with others in the sales department.

The same division of authority may be necessary or desirable in manufacturing plants where the work is concentrated in one group of buildings. Very often the master mechanic and his department in charge of plant maintenance can best be made responsible for the maintenance of the highway equipment. If the volume of road movement is fairly evenly divided between the other departments, then the master mechanic can supervise the operation of the highway vehicles as well.

Inter-Plant Movements

Goods in process, as distinguished from the finished product, form the main part of the inter-plant movement here considered. This is true whether the movement is from the vendor to the company plant engaged in fabrication or assembly, or, with a larger corporate organization, between specialized plants. Good management in either case would involve, first, a constant flow of material arranged to satisfy production schedules and keep down inventories of material in process; and second, the elimination of hand work and idle time of the trucks, by a close coupling of the highway vehicles and the materials-handling system of the industrial plant. The first of these is a matter of scheduling or dispatching to a large extent. The tendency with large plants is to reach out and pick up the goods at smaller vendors within local territories, say, within a radius of 15 miles. If the vendors are situated further away than that, then they take the initiative and send small shipments by motor carrier. Such service is available in a thickly populated industrial section from points as far apart as Cleveland and Buffalo or Chicago and Detroit, of the order of 300 or 400 miles.

The second requirement, involving the elimination of idle time and hand work, is being promoted by the design and layout of buildings. New factories put up since the war are usually designed for off-street and under-cover loading and unloading of motor trucks. Columns and posts are located to help and not hinder the truck movements. Platforms are being built the same height as the truck floors, even when this involves a ramp for the small and lower vehicles. A depressed-runway construction is considered a great advantage in the Chrysler plant, where a 51-in. concrete unloading ramp with depressed floors permits trailers to be backed against a platform exactly the height of the trailer floor. Electric industrial trucks can then be run directly on the floor of the large truck or trailer.

The magnitude of the annual trucking done by a large industrial concern is shown by the following figures, furnished through the courtesy of J. H. Myler, director of traffic for the Dodge Brothers Corporation:

Division	Work handled, lb.	Miles operated
Chrysler	433,880,911	1,093,097
Dodge	351,236,928	884,901
Plymouth	82,643,976	202,212
Totals	867,761,815	2,180,210

About 25 per cent of the materials for the Chrysler division is handled by the trucks of the inter-plant transportation department, while 70 per cent moves by rail or boat, and the other 5 per cent by trucking companies operating on regular routes.

Other materials-handling facilities can be brought directly to the truck, and are to a limited extent. Portable conveyors can easily be arranged to carry packaged goods directly into the truck body; a tramrail system, Figs. 2 and 3, that eliminates all lifting of dressed meat in and out of the truck, is used between Jersey City plants of the Swift Company by the Motor Haulage Company. The new R. H. Macy department store building in New York City, in addition to a 100-ft. truck platform, has two elevators on which loaded trucks can be moved to any floor.

The truck body itself may be removable, so that the load can

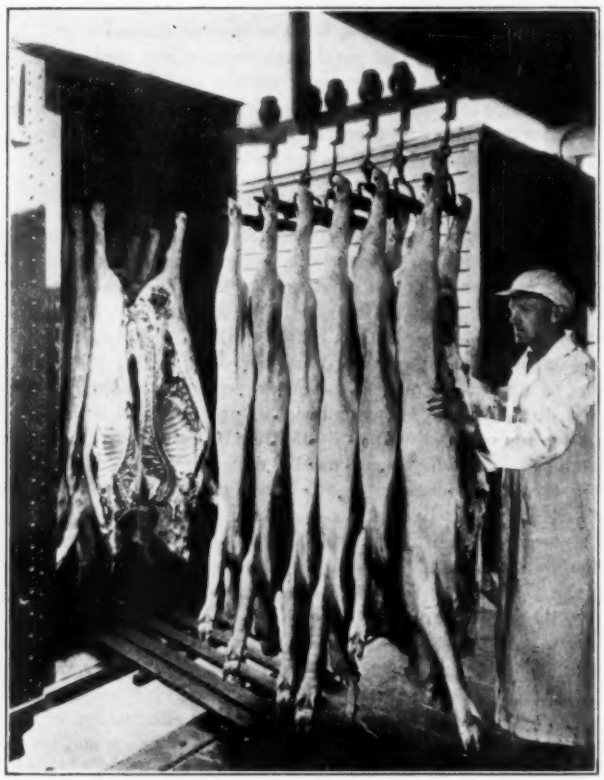


FIG. 2 SPECIAL BODY EQUIPMENT, LINKING UP WITH PLANT MATERIALS-HANDLING FACILITIES, SUPPLIED BY A COMMERCIAL HAULAGE COMPANY TO JERSEY CITY BRANCHES OF A LARGE PACKING COMPANY

be packed inside the plant or can be discharged at some point more convenient than the truck dock or platform. This work can be going on with extra bodies while a load is moving over the road. The International Motors Company gets the effect of a demountable body by the use of wheeled aluminum containers, Fig. 4. These carry castings from the company's foundry at New Brunswick, N. J., to its plant at Plainfield, 14 miles away. Fixed tracks are required for getting the container on or off the truck. If these tracks are not available, the container can be transferred to an ordinary road trailer, and then to the loading platform. The design is considered an improvement over the construction used by eastern railroads, which latter requires an overhead crane for transfer from truck to freight car.

Handling fuel and other supplies not part of the manufactured product is often a serious problem. The Lukens Steel Company has recently embarked on an unusual project for moving fuel oil from the refinery to its plant at Coatesville, Pa. The plant process continues 24 hours a day, and hence the delivery takes advantage of the commonplace but infrequently utilized fact that the highways are open at night as well as during the more normal working hours. Vehicles and their oil, fuel, repairs, and maintenance are supplied by a commercial haulage

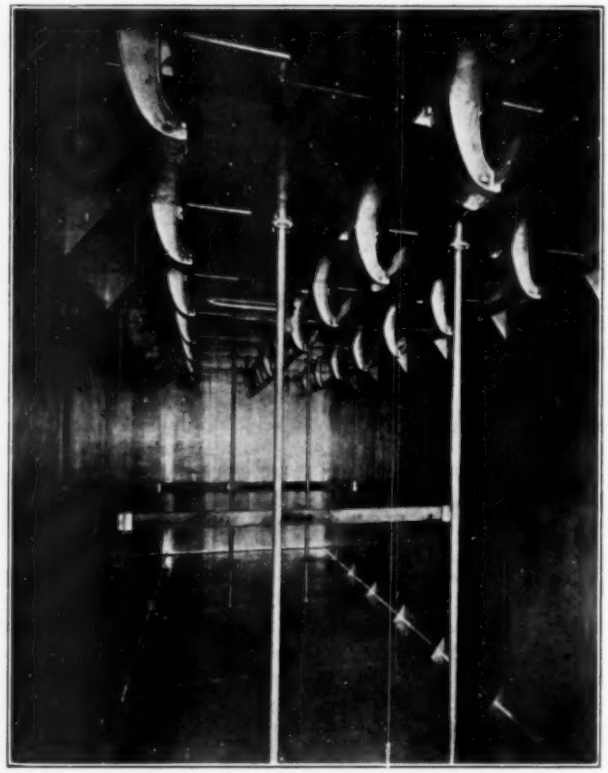


FIG. 3 OVERHEAD RAILS CARRIED ON BRACKETS SUPPORTED FROM THE ROOF OF THE TRUCK BODY. NOTE CROSS-PIECES TO SECTIONALIZE THE LOAD OF HOG CARCASSES



FIG. 4 CONTAINER OF 15,000 LB. CAPACITY USED FOR CARRYING CASTINGS FROM FOUNDRY TO ENGINE PLANT OF TRUCK MANUFACTURER. ONE MAN CAN DISCHARGE IT

company on a per-mile charge basis. According to a report in a recent issue of the *Commercial Car Journal*, the contractor charges about 0.6 cent per gallon delivered, while the railroad charged 0.89 cent a gallon. An estimated saving of $100,000 a year will be made, and this will soon offset the $30,000 the company spent for a concrete highway to connect the public road

with its storage tanks. Another saving is in handling the oil at the steel plant. It cools only about 30 deg. during the two-hour or 30-mile trip, and can be discharged without being heated. Previously, when railroad shipments were on the road possibly for several days, reheating was necessary. This movement is made in trains, Fig. 5, consisting of a tractor drawing one semi-trailer and another four-wheel trailer. These carry 2800 gal. and 2100 gal., respectively. Six White tractors and eight sets of Fruehauf trailers are assigned to the service, so that an extra pair of trailers can be stationed at each end while the others are on the highway.

A Sales-Department Adjunct

With the product finished and ready to ship, there enters the troublesome problem of physical distribution, one that requires all the best efforts of sales and traffic departments if the goods are to be laid down at the doors of the dealer or other customer at the lowest cost and, what is even more important, at the time and in the quantities wanted. The truck may serve by picking up the goods at the plant's shipping room and dropping them at the consignee's door, or if he has his way, at the back alley or other receiving entrance. For this work vehicles owned by the manufacturer may be used in metropolitan sections and their immediate suburbs, within a radius of 25 or 30 miles from the factory or warehouse.

The territory covered by "owned" trucks may be extended to a 75-mile limit when the shipment involves special goods or special handling of them. For example, the tank trucks used in hauling gasoline, Fig. 6, are not available for carrying general merchandise, and so the oil companies are forced to depend largely upon their "owned" service. When the drivers must also be salesmen, and perhaps stack, stock, and display the goods as well as collect for payment, the longer routes may be covered in vehicles devoted exclusively to the manufacturers' service. This would apply usually to goods of a perishable or semi-perishable nature—food products, bakery goods and the like, or to soft drinks—involving frequent attention to customers and a return of empty containers and bottles.

Some of the larger baking companies have a system by which the drivers buy the truck chassis while the company supplies the body. The drivers are then paid a percentage of gross sales as salary, plus an allowance for maintenance. They must pay for the storage of their vehicle, and keep it in first-class operating condition. This scheme seems to be used only when the vehicle is light and comparatively inexpensive. A more general practice is to require each truck put out for sales purposes to bring in a minimum return in the way of sales. If this is not attained, it usually means a careful study to determine whether the route is justified at all, or less frequent service can be given, or the sales ability of the driver is at fault.

Cooperation and Transportation

By far the larger part of present truck movement, at least of manufactured goods, is in conjunction with the older rail or water carriers. A manufacturer in Brooklyn, say, with a shipment destined for a hardware jobber in Phoenix, Ariz., may call upon his haulage company to move the shipment to the Bush Terminal, there to be transported by water through the Panama Canal. Arriving at San Pedro, Calif., there are fifteen or twenty truck operators waiting to carry the shipment to Los Angeles and into the terminal of the "Desert Express" trucking company, which makes regular trips over the 476-mile route to the capital of Arizona. There if the wholesaler happens to be disposed to send the complete shipment to a dealer, say, in Florence, Ariz., he can have the goods immediately transferred to a local motor carrier operating a network of routes out of Phoenix (see Fig. 7), Alabam's Freight Company, Inc., which finally sets the goods down at the hardware dealer's store.

If this same shipment happened to be consigned to a hardware dealer in Winner, South Dakota, the drayage company would still be called upon but would deposit the goods at a railway freight station where they would be loaded in a west-bound merchandise car for Sioux Falls, S. D., or possibly for Minneapolis first and then made up again in another car for Sioux Falls—after which a railroad-controlled trucking company would pick up the shipment and move it over the 224 miles to Winner, in the south central part of South Dakota.

Railroad Activities

As the economic place of the truck is beginning to be demonstrated, a few of the railroads are operating revenue road services. One of the first evidences of this cooperation has been "internal"



Fig. 5 Nearly 5000 Gallons of Fuel Oil Are Carried by This Road Train
(This form of transportation supplies the complete requirements for a large steel company.)



Fig. 6 New Form of High-Speed, Light-Capacity Delivery Is Being Adopted by the Oil Companies
(This vehicle can make 30 m.p.h. and carries 750 gal. of gasoline.)

use of trucks by the railroads. Trucks either owned or hired are handling movements of merchandise between freight terminals of a single or of more than one rail carrier. They are also being used to distribute l.c.l. shipments from one station to smaller points, where the truck is cheaper than the former peddler-car method. Truck applications of this kind have no direct effect on rates or on the contact of the shipping public with the railroad. Shippers still deliver goods at the carrier's station and consignees must pick them up there. What the truck does is to cut down operating expenses of the rail carrier and incidentally help the shipper by speeding up the through movement.

The change in attitude of the railroads toward the truck has undoubtedly been hastened by its success in moving non-revenue freight, such as the supplies formerly distributed by work trains or sometimes in revenue freight cars. The Great Northern, it is reported in recent issues of *Railway Age*, has 38 trucks scattered over its system, used for the movement of small lots of materials by its stores, maintenance, bridge, building, and other departments. The Southern Pacific operates a supply unit from its West Oakland headquarters. Once a month six trucks and thirteen trailers deliver and pick up material from sections, signal towers, and crossing watchmen in a territory of some 30 square

miles near San Francisco. Between these monthly trips short hauls are made to the stores, laundry, and commissary departments. The trucks cover about 4300 miles a month at an average cost of slightly under 23 cents a mile. This same railroad, according to a report presented last year to the American Railway Bridge and Building Association, estimates that motor trucks will save 50 per cent of the cost of moving materials between Chicago and Milwaukee. This has the advantage of the ordinary truck movement, in that late-afternoon pick-ups can be delivered at destination early the next morning. Two handlings of the goods are saved by placing a road trailer on a rail car for the line haul. (See Figs. 8 and 9.) Rates of 30 cents a hundredweight include free pick-up and delivery service on minimum shipments of 10,000 lb. If the shipment is more than 20,000 lb.

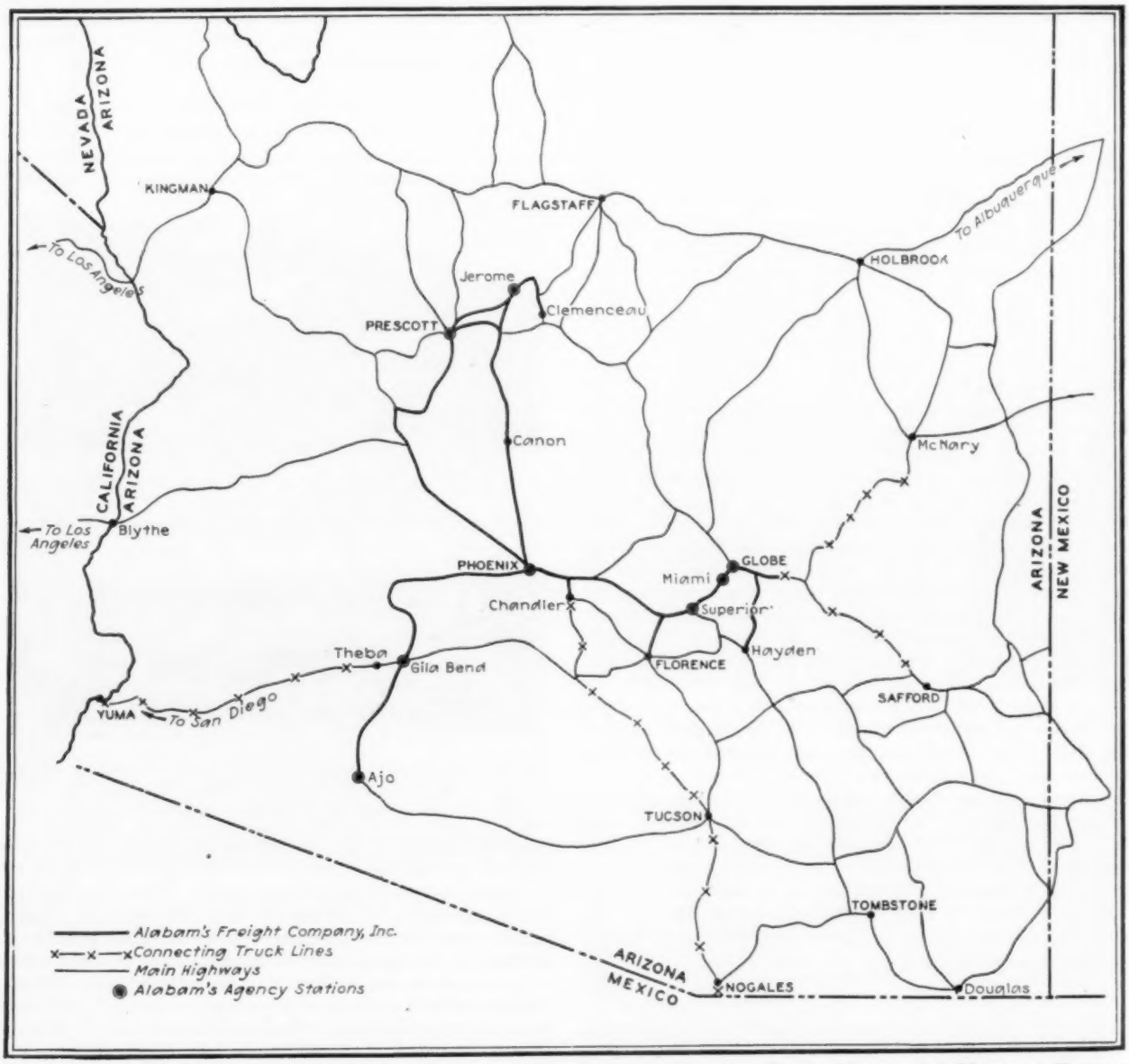


FIG. 7 FROM THE DISTRIBUTING CENTER AT PHOENIX A SINGLE TRUCKING COMPANY COVERS NEARLY 600 MILES OF HIGHWAY ON REGULAR SCHEDULES

with the motor car or push car, and 75 per cent of the expense of handling with work trains.

In taking to the highway for short hauls of their own small-lot materials, the railroads are adopting the same principle that the motor carriers in effect advocate by their operation of scheduled and other truck services.

The natural tendency of the railroads is to retain the line haul on rails and to make use of the truck for the movement at either end. Service of this kind has been worked out by the Chicago, North Shore, and Milwaukee Railroad on the 90-mile haul between Chicago and Milwaukee. This has the advantage of the ordinary truck movement, in that late-afternoon pick-ups can be delivered at destination early the next morning. Two handlings of the goods are saved by placing a road trailer on a rail car for the line haul. (See Figs. 8 and 9.) Rates of 30 cents a hundredweight include free pick-up and delivery service on minimum shipments of 10,000 lb. If the shipment is more than 20,000 lb. the rate is 20 cents a hundredweight. That this plan may be extended to cover other parts of the country is indicated by the tentative proposal of one railroad-owned motor carrier to span an 80-mile section of poor road on one of its routes by hauling the trucks on flat cars over the railroad.

The electric interurban railroads, which move such a large volume of manufactured products from factories in Ohio and Indiana to the automobile-assembling plants in Michigan, have issued tariffs indicating that pick-up and delivery charges may be absorbed in whole or in part by the rail rates on much the same

basis that trap-car service is given directly to industrial plants by the steam railroads. If the weight of the shipment and the revenue it involves are not sufficient, the shipper can have the goods picked up or delivered at this plant merely by paying a slight extra charge.

One interurban electric railroad in Michigan has acquired control of a trucking company which not only operates over regular routes, but also does a general city cartage business. But as a rule the interurbans turn the truck work over to a separately owned cartage concern, to which is paid a specified allowance. The use of this cartage service is optional with the shipper, who can use his own trucks at terminals if he so prefers.

The Pacific Electric Railway, serving a large part of southern California with its rail lines, has formed a subsidiary express company, designed to provide door-to-door service at rates that include the complete movement. Existing cartage companies are hired to make the pick-ups and deliveries, while the intermediate movement is over the rail lines. This service reaches some 50 cities, and within three months after it was started early this year, it was reported that 245 industries were being served. Of these, 210 had not previously used the Pacific Electric rail service.

Thus in the Central West and in California the electric inter-

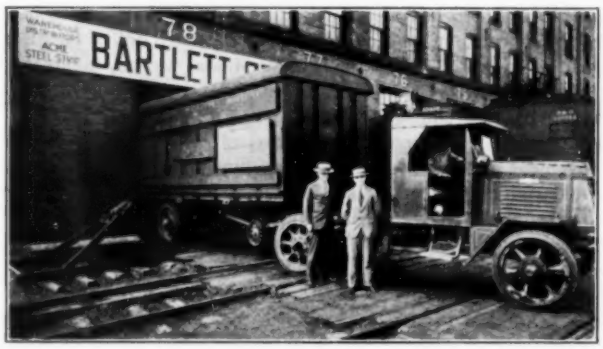


Fig. 8 Road-Trailer Service Over the Highway Extends the Service of an Electric Railroad to Chicago Industries

urbans are offering the store-door delivery available for years in Great Britain and Canada. This complete service was characteristic of the early development of the motor-carrier lines. The truck service is given through subsidiary companies by the Boston & Maine in Massachusetts, the St. Louis Southwestern in Arkansas, and the Chicago & Northwestern in South Dakota. But only a few of the steam railroads of the United States have seen fit to provide either the through or terminal truck service. An approach to it in New York City and St. Louis is given because of a combination of physical conditions and of railroad competition, and does not indicate any general adoption of the policy by the rail carriers.

As has been pointed out in this paper, something akin to store-door service is available in most cities by the employment of cartage companies. But the final step advocated by shippers is yet to come. The railroads would then be responsible for the complete movement. All shipments now moved by shippers or drayage companies to and from the freight houses would be handled by a single company. This might be a cartage company under contract with the railroad, or one owned by the latter.

The steam roads are not convinced that the service is a necessity, generally speaking. But where street congestion is constant and serious, where yards and freight stations are limited, the store-door service might help both the shippers and the railroads, according to one railroad authority. The number of vehicles for cartage and the number of freight cars would both be reduced. Quicker movement of freight would be possible, and economies would be effected by both parties. In any scheme of this kind all the road charges would be passed along to the shipper.

Freight-house facilities for l.c.l. deliveries could be reduced about one-half, one authority in the trucking business has estimated, with what he calls "regulated store-door delivery."[6] This would provide for the smaller shipments up to one or one and one-half tons. Deliveries could be made to the greatest number of consignees at one time and that time would be off the peak of automobile traffic in the business and shopping cen-

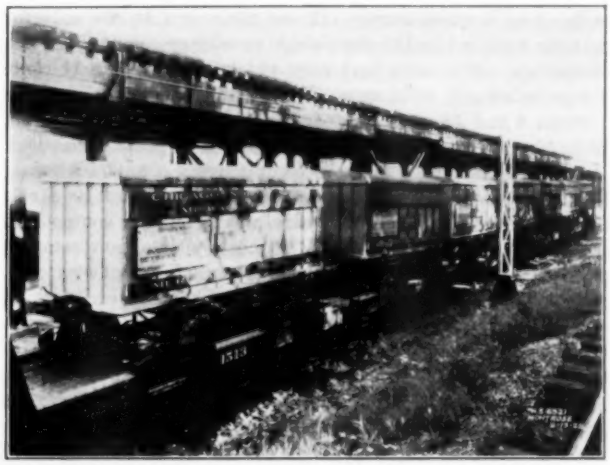


Fig. 9 Road Trailers Placed on Special Flat Cars for Line Haul Between Chicago and Milwaukee



Fig. 10 In the Mountains of Southern California, Not Penetrated by Railroads, the Motor Carrier Is an Essential Factor in Physical Distribution

ters. One vehicle might serve one building or one city block, whereas under the present uncontrolled condition the one vehicle may make collections or deliveries at such widely scattered points that the result is a large number of partly loaded trucks getting in each other's way and in the way of passenger automobile traffic.

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[6] Wm. J. Duffy, General Manager, Big Three Inc., Boston, Mass. at 1929 Transportation meeting of the Society of Automotive Engineers.

Commercial Motor Carriers

One industry that watches all its costs closely, namely, the department stores, has found it desirable both to hire and own trucks. These stores are in the habit of operating their own delivery vehicles, partly on account of the volume of movement available and partly because of the prestige their name carries on well-kept equipment. That this is not controlling, however, is shown by the fact that a separate organization (The Eleto Company) is maintained as the delivery department of some of the largest New York department stores.

The drayage conditions in 88 of the larger cities are reflected in a study made early this year for the traffic and receiving group of the National Retail Dry Goods Association. Of 135 stores replying to a questionnaire, 19 use their own trucks only for drayage work, while 110 use outside or cartage-company service exclusively. The rates paid vary widely, but average 11 cents a hundredweight, with most of the replies indicating amounts between 5 and 15 cents a hundredweight. A minimum of from 10 to 50 cents is charged for each shipment or package handled.

Attempts have been made to form delivery companies owned jointly by several retail stores or other shippers, but as a rule there have been too many owners and too much competitive spirit for these to work out well. Consequently a more common practice is for a specialist, such as a cartage or delivery company, to handle the work in city and suburban territory. A contract or common motor carrier makes the longer hauls. When such service is available, the ownership and exclusive use of trucks may easily become a luxury—and an expensive one. The owners are partaking in individual transportation, dished up in a most uneconomic style. The individual is too often one small box or package, while the transportation unit is waiting and willing to carry anywhere from a two- to a five-ton load.

The commercial service available to the manufacturer may reach practically every town or village in the metropolitan districts. One Chicago haulage company makes daily trips to 125 towns or communities. These are worked on eight different routes. About 40 miles is considered the maximum length of route. Since each one averages 50 stops, the 80-mile round trip represents a good day's work, sometimes 10 to 11 hours, for the driver. Quoted rates are 40 cents a hundred for the 40-mile haul, with a minimum of 75 cents per shipment. Included in this base rate is pick-up at the customer's premises and sidewalk delivery to the consignee. The pick-up work is done usually in the afternoon by delivery vehicles from short runs, or by trucks of the same company used mainly for city haulage. In fact, the suburban delivery is considered an extension of the drayage service to accommodate good city customers.

Most of the shipments handled by this company are sent prepaid, it is understood. More and more manufacturers and their branches are "absorbing the freight." This is perhaps a method of lowering selling prices, but the point of significance here is that with purchased service the delivery expense to be charged against each order is definitely known. This might not be the case if the work were handled by "owned" trucks. At least the actual expense would be harder to determine accurately, and in most cases would be greater.

Beyond the 40-mile suburban zone the motor carrier operating under permit or franchise from state authorities comes into the picture. Small shipments may be moved by bus companies primarily engaged in carrying passengers and their personal baggage; larger ones, by express or freight lines concentrating on the movement of property.

Packages carried by busses are limited in size, say, to 100 lb. weight and in volume to 10 cu. ft. Only a small amount of space is available and the service is intended to cover quick delivery of small-lot material at two or three times the rate charged by truck or rail. Ordinarily the movement is from terminal to terminal, although the driver may make deliveries to consignees directly on the route. A rate structure based upon weight (or volume) and distance is used by the larger bus companies. Special rates apply for newspapers, ice-cream containers, and other shipments requiring unusual handling. The charges for an express service recently announced by the Greyhound Lines on its Chicago-Muskegon division vary from a minimum of 25 cents for 10 lb. or less for the first 25-mile zone up to 45 cents for a haul of 200 miles. The charges in the 151- to 200-mile zone are shown by the following extract from the Greyhound express tariff:

Weight, lb.	Volume, cu. ft.	Rate	Weight, lb.	Volume, cu. ft.	Rate
1–10	.	$0.45	56–60	6	$1.15
11–20	1	0.55	61–65	.	1.25
21–25	2	0.65	66–70	7	1.35
26–30	3	0.70	71–75	.	1.40
31–35	.	0.80	76–80	8	1.50
36–40	4	0.85	81–85	.	1.60
41–45	.	0.95	86–90	9	1.70
46–50	5	1.00	91–95	.	1.80
51–55	.	1.10	96–100	10	1.90

Freight and passengers may be carried in a vehicle designed for combination service, as shown in Fig. 10. This is used on a mountain run of the Motor Transit Company out of San Bernardino, Calif. During the summer-resort season, goods and passengers are handled in separate vehicles, but at other times a single vehicle is sufficient.

Extensive systems of motor carriers concentrating on the movement of property over regular routes and on fixed schedules are developing in many sections of the country. These are often referred to as freight lines, but to a large extent they give an express service, with pick-up and delivery included in the tariff rates. Sioux Falls, S. D., Wichita, Kan., Phoenix, Ariz. are centers of networks, each developed under one corporate ownership. Another type of operation, comprising central terminals for truckers on different routes, is found in such places as Nashville, Tenn., Indianapolis, St. Paul, and Minneapolis.

The motor common carriers (they really are that since they hold themselves open to serve the public at large) establish their rates as a rule upon the basis of l.c.l. freight charges. These have been found fairly profitable for hauls up to 50 miles, but for longer trips are not usually adequate unless the movement is heavy in both directions. Most truck lines follow the railroad freight classification, and have special commodity rates dictated by their local conditions. Taken the country over, the rates vary with locality just as do those of the railroads. The following list gives class rates in cents per hundred pounds for a 50-mile haul:

	Class			
Location	1	2	3	4
Minnesota	31.5	26.0	21.0	16.0
California (southern)	45	40	35	30
Kansas	46	38	31	26
Indiana	46	39	31	23
North Dakota	53	45	34	28
Arizona	65	60	55	45
Texas	65	65	45	45
California (northern)	100	95	40	85

The spread between Minnesota and northern California may seem considerable, but the one is based upon l.c.l. freight charges, while the other is for haulage over poor roads to mountain resorts. Another difference is that Minnesota lines are offered business the year round, while in California most of the business is handled in the three summer months. The Minnesota Railroad Commission has established the local l.c.l. rates as reasonable

and maximum, and requires that five or ten cents a hundred be added to them for ground-floor, pick-up, and delivery service. In Kansas and Texas the rates are higher, of the order of 15 or 20 per cent, than charged by the railroad. This in the belief that the service (pick-up and delivery) as well as the cost of operation justifies the increase. The lines out of Grand Rapids, for which the Michigan rates are quoted, give free pick-up service only for 1000-lb. shipments. More and more motor carriers are adopting the practice of charging for picking up small shipments. Many shippers with trucks they use for city work, prefer to make their own deliveries at the truck terminal; the goods can then be handled at the most convenient time, and without congesting the shipper's loading dock with outside trucks.

That the inter-city trucking business is still in the individual-ownership stage, is shown by conditions in the automobile center of the universe. A compilation made by the Detroit Board of Commerce indicates that 68 carriers operating under permits from the State Utilities Commission have their terminal in the city. These have a total of 288 trucks or tractors. The average number of power units per carrier is less than five, it will be noticed, while 21 are listed as having only one truck. The largest company has 27 trucks and 46 trailers, and operates from Detroit to Lansing, Jackson to Pontiac, Jackson to Lansing, and Detroit to Jackson, Homer, and Albion.

By far the majority of operators in the inter-city trucking field have a radius of operation of less than 50 miles. This is borne out by an investigation made by the Railroad Commission of Texas, with the following results:

Length of route	Operators	Per cent
10 miles and less	9	3.41
20 miles and over 10 miles	55	20.84
30 miles and over 20 miles	58	21.97
40 miles and over 30 miles	48	18.17
50 miles and over 40 miles	26	9.84
60 miles and over 50 miles	14	5.31
75 miles and over 60 miles	16	6.06
100 miles and over 75 miles	12	4.55
150 miles and over 100 miles	21	7.95
Over 150 miles	5	1.90
Totals	264	100.00

From these figures it will be seen that 74.23 per cent of the operators cover 50 miles or less, while only 14.40 per cent cover 75 miles and more. The results apply of course directly to a large agricultural state, but are believed to be typical of most of the states in the country. In some of the industrial sections the movement between manufacturing establishments is justifying much longer hauls.

The increasing scope of the regular trucking services was pointed out in a report submitted by the Hon. Clyde L. Seavey of the California Railroad Commission to the 1929 annual convention of the National Association of Railroad and Utilities Commissioners. To quote from this report:

> A comparatively few years ago the motor truck was confined to hauling l.c.l. freight of a relatively high value for short distances varying from 35 to 75 miles, but in recent years the length of haul has been gradually extended until at the present time it is not unusual for shipments to move three, four, or even five hundred miles. Likewise the nature of the commodity transported is rapidly changing. Such articles as iron and steel, cement, and even crushed rock, which we ordinarily associate with the rail movement, are now being handled in trucks. Dairy products and other perishable freight move under refrigeration for distances in excess of 200 miles. Part of this movement is complementary to the rail haul, but a large part is tonnage directly taken from the railroads.

The truck transportation, according to Mr. Seavey, obviates the terminal handling and transportation cost, permits shipment in smaller units, and for short hauls at least results in a material saving in time. But he points out that while the truck type of transportation is needed, it should be stabilized to the same degree as other types of transportation have been. The private-contract carriers who cannot be placed under the jurisdiction of any regulatory body are indiscriminately cutting rates below the rail rates or the common-carrier truck operators subject to regulation. Many state commissions have received complaints from shippers utilizing the private-contract carriers who have been unable to obtain redress for loss and damage to their shipments or have been unable to obtain a settlement of C.O.D. collections, the report indicates.

The remedy for this situation, which is more or less prevalent all over the country, is largely in the hands of the shipping public. If they will patronize the regular carriers, whether motor or rail, because of service rendered and facilities available, and not take advantage of bargain reductions, they will quickly put the established carriers, particularly in the trucking field, on a basis where they can be of the best service to the public.

In conclusion, the author would call attention to the economic necessity of (1) wise centralization of authority when "owned" trucks are operated; (2) using a combination of road and rail services for long hauls of small-lot shipments; and (3) patronizing well-organized motor carriers for concentrated shipments between plants and for the last stages of physical distribution.

Discussion

CLINTON BRETTELL.[7] On the eighth page it is said that where merchandise was moved by "owned" rather than "hired" trucks "the actual expense would be harder to determine accurately, and in most cases would be greater." The writer's experience as a large fleet operator does not coincide with these statements, inasmuch as large fleets could afford to employ trained transportation and maintenance men and to enjoy all the economies of large purchasing power, specialized equipment, etc.

A representative of an automobile truck company says that small electric cars could be operated 35 to 40 miles daily with entire safety. The writer's experience in the Macy fleet is that 35 miles under ideal conditions is the maximum safe limit for small electrics, although higher mileages are occasionally attained.

The many economies of the electric over the gas truck were pointed out in the paper. The writer's comment is that the lack of flexibility and "cruising radius" of the electric, unless it had year-round work on short hauls, would be a serious handicap to its economy. It is the experience in the Macy fleet, particularly with the advent of cheap light gas cars, that while these cars might be slightly more expensive for a couple of months of the year when they would be operated on short runs and in traffic congestion, their adaptability to long-run work the balance of the year, where electrics could not be used but would have to lie idle, would give an overall advantage over the electric under those circumstances for the year as a whole.

A representative of a trailer manufacturer presented the many advantages of trailer operation. The writer's experience with demountable bodies instead of trailers, which seem to give many of the benefits of the tractor-trailer combination with the added advantage of being able to move the bodies close to the loading points and to various floors in the building, combined with easier handling in congested traffic in the part of the city where the Macy store is located, proves the demountable body a more desirable unit for that purpose.

JAMES W. COTTRELL.[8] The success of a company-owned motor-

[7] R. H. Macy & Co., New York, N. Y.

[8] Technical Editor, *Commercial Car Journal* and *Operation and Maintenance*, Philadelphia, Pa.

truck fleet often depends on its assignment in the organization and the amount of cooperation between it and other departments of the business. In most cases, the fleet should have a separate identity and should be able to show a profit. If each department of a business owns and operates its own trucks, each department will try to keep on hand enough trucks to meet the maximum demand of the department. This of course is not an efficient arrangement.

Mention has been made of the desirability of forming a separate subsidiary company to own the motor-truck fleet. An example of such a separate company is the Equitable Auto Company, of Pittsburgh, which supplies motor trucks for the electric, gas, and street railway companies of Pittsburgh. This company operates a sort of drive-yourself service, merely furnishing vehicles which other allied companies operate. This drive-yourself plan works well in many instances where the using department prefers to furnish and control the drivers.

The value of a separate fleet organization compared with the plan of separate department "ownership" and management of trucks is illustrated in the experience of a large manufacturing company in Trenton, N. J. A few years ago several different departments had trucks, and there was no arrangement for cooperation between departments. As a result, whenever a department had need for a truck, a man would go out and stand in the driveway outside the factory and hail the first truck driver who came along and induce the driver to come in and do the hauling for that department.

A keen truck dealer made an analysis of the transportation requirements of this plant and suggested the formation of a truck transportation department serving the other departments. The suggestion was carried out, and the newly established department furnished better transportation facilities at less cost. Incidentally, the number of trucks required was less than under the former arrangement.

While it is obvious that cooperation between different departments using motor transportation and the fleet department furnishing the transportation is desirable, the fleet department is not always given full recognition.

The fleet superintendent of a large dairy in the Middle West had an opportunity to show the value of cooperation between other departments and the fleet. He attended a conference of department heads and heard one of the branch managers bring up the question of hauling ice to the branch. The manager, after shopping around, obtained the price of 10 cents per 100-lb. for hauling the ice to the branch. The branch manager thought this a very reasonable price. The fleet superintendent offered to do the work for 5 cents per 100, and of course was given the job. Afterward, he let it be known that he could do the hauling for nothing, if necessary, as he has trucks going from the downtown section to the branch empty each day, a fact which the branch manager did not know.

The convenience of truck transportation often justifies its use, even though it costs more than other mediums of transport. If export shipments must "make" a certain boat or a special shipment must go on a certain train, trucks frequently are used between factory and pier or railroad station, even though the shipping points may be many miles' distance from the factory.

A very successful inter-city trucker has kept his customers against price cutting by furnishing a high grade "always-on-time" service. A large part of his hauling is from manufacturing plants which must rely upon regular shipment.

Convenience is one of the factors favorable to the use of trailers in certain fields. Trailers are usually looked upon as a means of increasing the pay load of a given vehicle or of reducing idle time of the power vehicle. In certain applications they have the important advantage of helping shippers. An illustration of this condition is the shipment of tires from factories in Akron, Ohio, to automobile factories in Detroit. Tires come out of the plant in an almost steady stream and are moved across the shipping platform into trailer bodies, which become large bins on the platform. This arrangement reduces handling on the platform, as it is not necessary to unload the tires on the platform and then reload in a vehicle.

Demountable bodies have been used successfully for some time on heavy-duty trucks and are also in use on light trucks. In the heavy-duty field the Cincinnati Motor Terminals Company uses demountable bodies for the exchange of l.c.l. freight between railroads entering the city of Cincinnati. These bodies are handled by overhead cranes, installed in the freight stations for that purpose.

An example of use of demountable bodies on light trucks, in which the body becomes a part of the plant served by the truck, is the James Vernor Company, of Detroit, Mich., makers and bottlers of ginger ale. The bodies, which are used interchangeably on Ford and Chevrolet trucks, are loaded and unloaded by an electric crane on a monorail which extends over the sidewalk. When the truck arrives, the body is hoisted from it and placed on a dolly inside the plant. This dolly and body are moved by hand to an escalator where cases are unloaded and transported to the second floor. The empty dolly and body are pushed to the other side of the room where cases are delivered from the plant by a gravity conveyor. The load is made up in accordance with a shipping order and held on the dolly until the next truck arrives. Actual time required for exchange of bodies is less than three minutes.

An overnight haul frequently is the unit of measurement of truck transportation. Today's production in one factory is delivered to another plant or to destination by the next morning. Truckers seek to extend their field of activity by extending the distance over which a shipment may be carried between, say, 6 p.m. and 7 a.m. To meet this requirement, manufacturers are offering high-speed heavy-duty trucks. A 10-ton truck designed to travel at 35 miles per hour and one of 8-ton rating designed for the same speed were recently put on the market and more are expected to follow. It is obvious that trucks of this capacity and speed greatly extend the radius of operation of "overnight" trucking.

MARTIN J. CONWAY.[9] The author has given an excellent paper on motor-freight movement as undertaken today and to be expected in the future. The writer cannot do better than to substantiate the information the author gave in referring to the hauling of heavy fuel oil.

The Lukens Steel Company owns and operates a fleet of 14 trucks of various makes and sizes for interplant haulage and short-haul delivery of steel plates and flanged heads to the many customers who in these days of low inventories require speedy deliveries.

Practically all of the raw material moved into the plant and of the finished plates moved out of the plant is handled by rail, which requires an in-and-out movement of about 2600 cars monthly.

One item in this car movement was the shipping into the plant of 40,000,000 gal. of fuel oil yearly from Marcus Hook refineries, a distance of 39 miles from refinery to the steel plant, entailing a freight bill of $356,000 yearly. This oil movement presented a real trucking problem, and several studies were made of the possibilities of a saving, as the route over which the motor trucks would have to pass was anything but desirable. The only favor-

[9] Fuel Engineer, Lukens Steel Company, Coatesville, Pa. Mem. A.S.M.E.

able point was that there is a good hard road for the total distance.

Accordingly with the aid of the engineers from the equipment manufacturers, Lukens Steel Company made a survey of the proposed operation which entailed studies of the minimum weight and horsepower of equipment which would carry the maximum pay load, which would be within the highway laws of the Commonwealth of Pennsylvania, and which would operate safely and easily, guarantee uninterrupted service, require the lowest maintenance cost over a prolonged period, and present a pleasing appearance on the highway. All of these features received their share of study, as the route over which the trucks were to travel had all of the elements in its short length that could be expected on a long cross-country run—steep grades, short-radius curves, crowned roads, narrow congested highways, traffic lights, and railroad crossings. (See Fig. 11.)

After ascertaining that the operation of transporting fuel oil to the plant could be performed with motor-truck equipment with as much ease as with railroad equipment and with the assurance

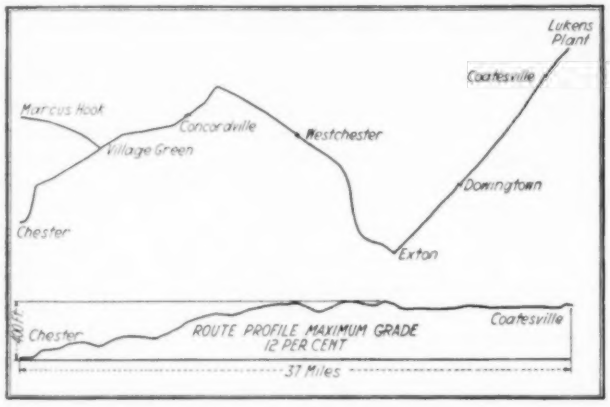


FIG. 11 MAP OF THE ROUTE

of an uninterrupted supply at a saving in the cost of transportation, the Lukens Steel Company decided that the proper course of procedure would be to contract for this service through one of the large haulage contractors whose business it is to operate, superintend, and service contracts similar to the one the Lukens Steel Company wished to place.

After a thorough investigation of the proposition, submitted by six bidders, all being qualified by repute and financial stability to undertake the work, the contract was given to the Motor Mileage Corporation, whose organization has since proved more than equal in meeting all emergencies which of necessity arise in an undertaking of this magnitude.

The Motor Mileage Corporation equipment for this work consists of six Model 59 White truck tractors, six Fruehauf semi-trailers, six Fruehauf four-wheel trailers, one Model "AP" Mack tractor truck, and one Highway four-wheel trailer for this unit. The specifications were as follows:

WHITE EQUIPMENT SPECIFICATIONS FOR MODEL 59 TRACTORS

Engine used in tractors: Bore, 4 3/8 in.; stroke, 5 3/4 in.; piston displacement, 518 cu. in.; maximum net brake horsepower, 100 at 2000 r.p.m.; maximum torque, 320 ft-lb. at 1000 r.p.m.; compression ratio, 4.03.

Reduction range (combination, transmission, and rear axle): 8.9–1 to 109–1 in seven steps.

Range in ability (ability being expressed as a ratio of tractive effort at the tractor driving tires to the gross train weight): When loaded to 72,000 lb. gross, 1.7 to 22.6 per cent; road speed of train at 200 r.p.m., 28.3 m.p.h. to 2.3 m.p.h. in seven steps.

Tire equipment used: 42 × 9 dual pneumatics on driving wheels of tractor; all other tires, 40 × 8; total number of tires on train, 18; total number of 40 × 8 tires, 14; total number of 42 × 9 tires, 4.

Braking: Westinghouse air-actuated brakes on all wheels of tractor, on two wheels of semi-trailer, on two wheels of the four-wheel trailer.

Safety devices: Airbrake system so designed that, should trailer break loose, brakes become automatically set on trailer; safety chains provided between semi-trailer and four-wheel trailer; tractor provided with two legal headlights, two marker lights, and rear vision mirror; trailers provided with combination rear marker light and tail light; tanks painted on end to attract attention of vehicles driving in same direction at night and to show the same as dead-end sign on the highway.

MACK EQUIPMENT SPECIFICATIONS FOR MODEL "AP"

Chassis: Six-wheel chassis, four-wheel drive; driving units, chain and sprocket drive.

Wheelbase: 165 in. between front and first set of rear wheels; 52 in. between two rear sets of wheels.

Weight: Chassis weight, 15,000 lb.; gross load allowed in the State of Pennsylvania, 36,000 lb.



FIG. 12 MODEL 59 WHITE TRUCK TRACTOR, FRUEHAUF SEMI-TRAILER, AND FRUEHAUF FOUR-WHEEL TRAILER



FIG. 13 MODEL "AP" MACK TRACTOR TRUCK AND HIGHWAY FOUR-WHEEL TRAILER

Tires: 40 × 8 front and 40 × 8 dual rear on each of four rear wheels; pneumatic tires.

Brakes: Service brakes on four rear wheels; type, Westinghouse air brakes; internal expanding brakes; brake surface, 574 sq. in.; emergency brake, 16-in. disk on propeller shaft.

Front axle: Center-point steering; reverse, Elliott.

Rear axle: Two solid I-beams, drop forged.

Wheels: Steel disk.

Transmission: Selective, four speeds forward and one reverse; Hypoid gear jackshafts.

Frame: 8 × 3 × 5/16 in. chrome-nickel pressed steel, heat treated.

Gasoline tank: 40 gal. capacity.

Starting and lighting: 12-volt Northeast system; 135-watt generator.

Motor: Model "AP," six cylinder; bore, 5 in.; stroke, 6 in.; brake horsepower, 144 at 1600 r.p.m., 155 at 1800 r.p.m., 159 at 2000 r.p.m., piston displacement 706.86 cu. in.; compression ratio, 4.78. to 1; cylinders cast in block; cylinder heads cast in pairs; governor speed, 1650 r.p.m.; crankshaft bearings, 3 7/16 in. diameter; crankshaft counterbalanced with balance weights forged integral; timing gears, drop-forged chrome-nickel steel, case hardened.

Magneto: Robert Bosch.

Carburetor: Stromberg.
Radiator: Finned tube, back of engine; air circulation by blower on flywheel; thermostat control on water circulation.
Speed: Maximum speed, 28 m.p.h.; average speed, 18 to 20 m.p.h.
Driving ratios: First speed, 57.92 to 1; second speed, 30.32 to 1; third speed, 16.02 to 1; fourth or direct, 9.05 to 1; reverse speed, 69.82 to 1.

The oil hauled by this equipment is the heaviest grade of Bunker "C" produced, ranging from 3 to 10 deg. B., and difficulty is experienced in pumping it at normal temperatures.

Tractors and semi-trailers were included as part of the equipment because it was thought necessary that a full train should be uncoupled during unloading and the tractor be released to take back the empty train while the oil was being heated preparatory to unloading.

Until the present it has not been found necessary to uncouple the tractor from the train for this purpose. As soon as the train arrives at the unloading platform, steam is connected to the coils in each tank at the same time that the unloading connection is made. Steam is turned on, and the unloading pump started simultaneously. This arrangement heats the oil sufficiently while unloading to prevent delay. Another feature is the fact that the oil, being loaded hot, drops only approximately 30 deg. while in transit, the time averaging $2^1/_2$ hours. During the hot summer months it was not necessary to use steam at the unloading platform because the temperature drop en route did not exceed 15 deg.

Author's Closure

Probably the best way to answer Mr. Brettell's opening statement is to quote completely the statement of the paper with which he disagrees. This follows: "More and more manufacturers and their branches are 'absorbing the freight.' This is perhaps a method of lowering selling prices, but the point of significance here is that with purchased service the delivery expense to be charged against each order is definitely known. This might not be the case if the work were handled by 'owned' trucks. At least the actual expense would be harder to determine accurately, and in most cases would be greater."

When the delivery is handled by purchased service, the shipper ordinarily pays separately for each package or order. The cost, therefore, is very clearly and definitely known. But when the shipper's own trucks are used, the process of determining costs is much more complicated. It is difficult to allocate general or overhead items of expense to the Delivery Department. Even though the total costs are included, there is no way of determining unit cost for an individual order or delivery, except by dividing total number of orders and deliveries into total delivery costs. This method of taking averages may be satisfactory for practical purposes, but certainly would not give as accurate results as when the delivery cost for each package is paid for separately.

The other point with which Mr. Brettell disagrees is that: "the expense . . . in most cases would be greater." As the paper repeatedly asserts, it relates to the application of motor trucks for and by manufacturing establishments.

In the majority of instances, trucks in this service would carry small-lot shipments to rather widely scattered consignees. The chances are very great, therefore, that the commercial trucking companies could offer a less expensive service because of their ability to carry good-sized loads on frequent schedules. Their ability to do this, of course, is based upon service to a large number of shippers.

The paper makes a statement that fuel oil, referred to by Mr. Conway, can be unloaded without reheating. Mr. Conway indicates that this is possible, however, only in the summer months, but that at other times of the year reheating is necessary. He describes an interesting arrangement by which the steam for heating can be turned on and the unloading started simultaneously. This gives practically the same effect as if sufficient heat could be retained during the trip for unloading, as is possible during the summer months.

Economics of the Electric Truck in Delivery Service

By H. L. FORMAN,[1] MOUNT VERNON, N. Y.

THE electric truck is a vehicle of specialized application. It can be used most advantageously under the following conditions:

1 A fleet operation.

2 In congested areas where speed is automatically limited by traffic conditions.

3 On regular fixed routes of limited mileage.

4 By established companies which can foretell with reasonable certainty that the delivery conditions of their business will remain approximately constant, and which therefore are justified in the initial investment, purchase of charging equipment, etc.

In this specialized field the modern electric has definitely proved its economic value. An analysis indicating its proper application and comparative operating costs against other types of equipment shows these to be based on inherent physical and mechanical characteristics. Before discussing these, however, it would seem essential to define the standard of cost comparisons.

Transportation costs may be kept accurately and elaborately, and yet be vague and meaningless for interpreting truck economic values. This is because truck costs are usually expressed in terms of "cost per mile" or "cost per package." Both these accepted "yardsticks" of truck working values are unreliable. For example: Two trucks both deliver 1000 lb. of bread. Truck 1 travels 10 miles a day at a cost of 20 cents a mile; truck 2 covers a 40-mile route at a cost of 15 cents a mile; but when truck 2 is put on the route of truck 1, the cost becomes 30 cents a mile. Obviously, cost per mile becomes meaningless as an index for determining comparative truck economies. Similarly, cost per package is equally uninformative. Two identical milk trucks deliver their loads within the same mileage. Truck 1, because of the distance between stops and the class of trade served, might deliver half as many bottles as truck 2. Delivery cost per package would wrongly show that, with these identical trucks, one costs twice as much to operate as the other.

It is fundamental that the only sound basis for determining comparative vehicle economies is that of doing the same work under the same conditions.

Bearing in mind the specialized field of electric-truck application and the index by which economic values are compared a summary of many different users' statistics indicates the following electric-truck advantages:

1 *Flexibility of Chassis Construction Which Permits a Special Body Designed for Maximum Driver Efficiency.* A large user of all kinds of delivery equipment in New York, referring to his electric fleet, says: "Adaptability of chassis and body design is by far the most important consideration, because the difference in operating costs between vehicles is negligible compared with the cost of the driver's time in delivering goods."

2 *Suitability of the Electric to Operate in Congested Areas.* The same operator summarizes these features as follows:

(*a*) The driver is freed from mechanical worries, as all he

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Contributed by the Materials Handling Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

can do is to move one lever forward and backward for ahead or reverse, and to apply a brake. This is against 12 separate movements in going from low to high gear on a gas truck, in which three levers or pedals operated synchronously by one hand and two feet are used for every traffic and delivery stop. (The starting and stopping of the motor is in addition to these movements.)

(*b*) The mechanism of the electric is not affected by weather conditions. It has no carburetor to adjust, or lubricants to be changed, or water-cooling system to protect.

(*c*) When it is considered that the entire power plant of the electric is almost identical with the self-starter superimposed on the gasoline engine, its comparative simplicity is apparent.

(*d*) The horse and wagon occupies 65 per cent more space and the gas truck about 30 per cent more space on the street than the electric of same capacity. This means better parking facilities, shorter turning radius, and easier manipulation in traffic.

There is, incidentally, a recognized public economic benefit from these factors, as well as other physical characteristics of the electric such as cleanness, odorlessness, and quietness. Simplicity, lesser liability to accident, and fewer road breakdowns mean greater reliability and a smaller number of reserve delivery units.

3 *Housing Economic Advantages.* The fact that the electric requires about 25 per cent less garage space than the gas truck and approximately 50 per cent less floor area than the horse and wagon is a vital cost consideration where real estate values are high. A recent example of this point was furnished where condemnation proceedings eliminated one of two buildings, both of which were necessary previously to house the total horse and automotive equipment. It was found that the smaller space occupied by the electric enabled the entire housing to be done in the remaining building. Furthermore, the company's architect pointed out that, due to the selection of the electric rather than gas equipment, no expensive building alterations were necessary.

4 *Advantageous Electric Insurance Rates.* Replying to a query on this subject by a large truck user, their insurance broker wrote as follows: "On liability and property damage, casualty underwriters allow a 25 per cent discount from gasoline-automobile rates. Fire insurance is not necessary, but even if it is carried it will be 50 per cent less than the gas truck. Fire insurance on buildings used for garage purposes varies as follows: Ordinary and fireproof buildings 50 per cent less; auto-sprinklers, 20 per cent less; fireproof auto-sprinklers, 15 per cent less. Theft rates are 75 per cent less than gas."

5 *Accuracy With Which Electric Truck Costs Can Be Budgeted.* There are fewer variable cost factors with electrics. Its chassis life is indeterminate, but proved to be from 10 to 20 years. Tire costs are less due to limited speed with more gradual application of power, and they can be predicted accurately on the basis of tire guarantees. Electric current for charging is computed on a fixed-contract-price basis that is, constantly decreasing throughout the country, is less liable to driver waste, and may be estimated closely on a yearly mileage basis. Battery costs, because of definite life guarantees, can be set up as a fixed item of cost. The only variable of expense is that of mechanical maintenance. In this connection the number of wearing parts of the electric chassis is so limited and the replacement and repair records on these are so comprehensive that they can be approximated within extremely narrow limits. An example of the accuracy with which operating costs can be budgeted was furnished by a large concern in the South. Before the purchase of a fleet of 90 electrics, detailed estimated operating costs were set up. At the end of three years the annual audits showed that the actual realized figures varied less than 1 per cent from predictions.

Simplified Comparative Operating Accounting. The easiest direct comparison of depreciation and maintenance costs can be made by eliminating from consideration all items common to both the gas and the electric truck. This means disregarding bodies, wheels, tires, frames, axles, springs, steering mechanisms, brakes, shop equipment, etc. (Such an arbitrary cancellation discriminates against the electric, because its limited vibrationless speed directly lessens upkeep and increases life on all parts.) There is now left all that differs—the two motive systems. With the electric, this is the storage battery and electric motor. With the gas truck, this is the engine, cooling system, starting-lighting-ignition system, fuel system, clutch, and transmission. On the battery and motor, the annual depreciation and maintenance is a fixed known sum, depending on the size of the unit. It is a figure, in general, that will vary from 30 to 50 per cent less than similar items of maintenance and depreciation on equivalent gasoline units.

Throughout this entire analysis, specific cost figures have been avoided. Such figures are relative; they involve many unknown and variable factors; and they seldom express comparable values. Instead, it is sound and logical to go behind the figures to the underlying facts which govern figures. Summarizing these facts, the economic place of the electric depend upon:

1 Its adaptability for delivery efficiency
2 Its suitability for operation in congested areas
3 Housing (garage) advantages
4 Lower insurance rates
5 Definite, predetermined, less-variable costs
6 Lower maintenance and depreciation.

Therefore, bearing in mind every phase of the limitations of proper electric-truck application, and aware of the only criterion by which delivery economies can be measured (cost per same work done), one can analytically determine where and how the economic advantages of the electric vehicle in delivery must be realized.

Economics of the Electric Street Truck

By L. A. DeMORE,[1] CHICAGO, ILL.

FOR general business purposes in metropolitan districts the motor truck has practically replaced all former horse-and-wagon installations and is now the chief means of merchandise transportation. True, there are yet in service a relatively small number of horse-drawn units, but these remaining few are feeling the pressure of specialized motor units, which will undoubtedly finish the horse-replacement program.

Two general types of motor trucks are in common use, each with its own peculiar advantages and fields of service—namely, electric trucks and gasoline trucks. The question of proper selection of the type of truck is very important if the operation of the business is to be conducted along lines of strict economy.

It is the purpose of this paper to deal with the characteristics and economics of the electric truck. At the start, there are admitted to be three outstanding limitations to the general use of electric trucks, namely:

1 *Limited Cruising Mileage.* The electric truck, deriving

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its power solely from a storage battery, is limited in the cruising mileage by the amount of energy contained in the battery. Under certain conditions two sets of interchangeable batteries can be used, which will enable the truck to be kept in 24-hour operation, and the limitation of mileage will be removed. However, this is only practical where the truck is in frequent touch with its home base. Interchangeable batteries are in daily use by a number of companies, among whom may be mentioned the Railway Express Agency and the Curtis Publishing Company.

2 *Limited Speed.* The maximum speed of the electric truck is built into it by the manufacturer and cannot be easily altered by the operator. What this speed is in miles per hour is largely determined by the work to be done. Electric trucks are in operation at speeds varying from 22 miles per hour on light- and medium-duty trucks down to 10 miles per hour on the heaviest trucks. Some variation in speed can be provided by the manufacturer to meet certain conditions. The variation usually

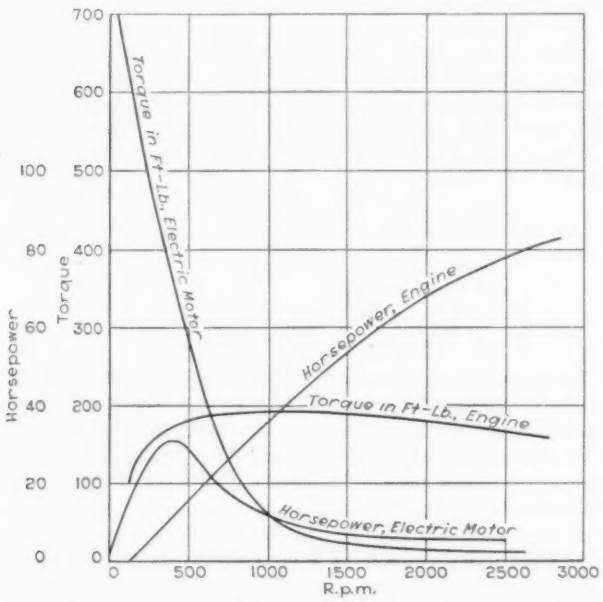


FIG. 1 CURVES SHOWING TORQUE AND HORSEPOWER OF A MODERN AUTOMOTIVE ENGINE AND AN ELECTRIC-TRUCK MOTOR

is accomplished by increasing the number of cells of the battery. This limitation of speed is ofttimes a tremendous selling advantage, as well as of particular economic value to the user, as it is the direct cause of lower insurance rates due to lessened accident hazard, lower maintenance, and longer economical life on account of decreased wear and tear. On such work as city routes, making hundreds of stops per day in a limited area, high speed is of absolutely no value. On the other hand, due to there being no clutch or transmission to operate and having an inherent fast pick-up, the electric truck on such work and in traffic congestion will actually maintain a higher average speed than is possible with other types of equipment, and part of its economy is due to such time saved.

3 *High First Cost.* To the average intelligent business man this should not be a limitation, but due to the fact that so few concerns keep anywhere nearly accurate costs of operation, the item of first cost is ofttimes given considerable weight, and the item of lower operating costs is thereby not made the deciding factor in the selection of the type of equipment. Many times a prospect will make the statement that it is all right for a larger successful electric-truck user to buy electric trucks because it has a lot of money. He does not appreciate the fact that the reason for the success of the larger company is most likely due to its keeping accurate records by which it determines its policies. The purchase of high-priced equipment is not because the company happens to have plenty of money, but because it knows that money is made only by using the best and most economical tools available in the business, irrespective of first cost, whether these tools be manufacturing machines, motor trucks, office machines, or any other equipment necessary to the business.

So much for the apparent limitations. What effect have they on the proper field of operation of the electric truck?

Let us accept the limitation of cruising mileage as that of one average battery. The limitation then means that a day's work must be accomplished within a daily mileage of, approximately, 45 to 50 miles on a $^3/_4$- to 1-ton truck down to a daily mileage of, approximately, 35 to 40 miles on a 5- to $7^1/_2$-ton truck. Such a limitation leaves as suitable work for the electric truck any route operating in a restricted area, in congested traffic, or having many stops. Among these, the most numerous are as follows:

1 Retail milk-delivery routes
2 Wholesale milk-delivery routes
3 Retail house-to-house bakers' routes
4 Wholesale store-delivery bakers' routes
5 Laundry routes
6 Retail ice-delivery routes
7 Wholesale ice-delivery routes
8 Department-store parcel-delivery routes
9 Department-store warehouse to substation deliveries
10 Chain-store deliveries.

In addition, the electric is also economically suited for:

11 Inter-plant haulage
12 Freight-station haulage
13 General urban express and trucking work
14 In general, any work now being done by the few remaining horse-drawn units.

Considering the foregoing as the legitimate field for the use of the electric truck, what, then, are the economies of operation which it will effect? In order to appreciate them, let us first have a simple picture of what the electric truck is.

Mounted under a pressed-steel frame is a conventional front axle with its springs, bearings, and wheels; also, a rear axle with its springs, bearings, and wheels. In its simplest form the truck has within this rear unit an electric motor and reducing gears which take the driving power to the wheels. The foregoing elements include all of the running parts in the truck.

To complete the vehicle a battery is slung below, in a compartment which serves to truss the frame; a controller is installed for manually regulating the flow of current from the battery to the motor; conventional steering and braking devices are added.

Now we have an electric truck; its simplicity is apparent. The motor is permanently connected, through gears of fixed ratio, to the wheels. When the truck is at rest, the motor is at rest.

Now, with this picture, let us look to the economies which result, and which are as follows:

1 *Low Depreciation.* The present-day electric truck should maintain economical service for not less than 15 years. When we assure that our company has a large number of trucks in operation today that are 15 years old or older, and weight is given to the improved designs, material, and methods which go to make up the present-day vehicle, one can appreciate that the economical life of the electric is practically indefinite. For accounting purposes, electric trucks are usually depreciated

over a 10-year life, which is certainly conservative. This 10-year life will usually represent an average of less than 100,000 miles.

2 *Low Maintenance.* Being so simply constructed, with few moving parts and with ample factor of safety from a load-carrying standpoint, very little labor or renewal of parts is required to maintain an electric truck. One man will easily do all maintenance and repair, except washing, on a fleet of as many as 35 electrics and still not be rushed for time.

3 *Low Insurance Costs.* There is practically no fire or theft hazard in the electric truck, and this is reflected in the underwriters' rates on fire and theft insurance. The average rate is about 50 cents per $100 valuation on 80 per cent valuation, and the rate does not increase with age of truck. Also, due to ease of control and safe maximum speed, there is a very low accident hazard, and this also is reflected in public-liability and property-damage insurance, the rates being 25 to 33⅓ per cent lower than for the corresponding size of gas truck.

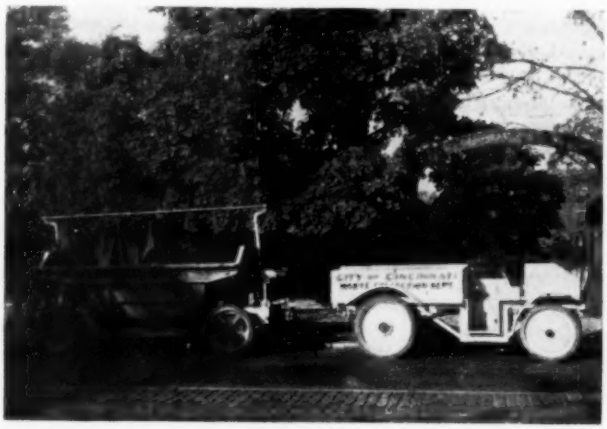


FIG. 2 ELECTRIC TRACTOR WITH TRAILER USED IN MUNICIPAL WORK

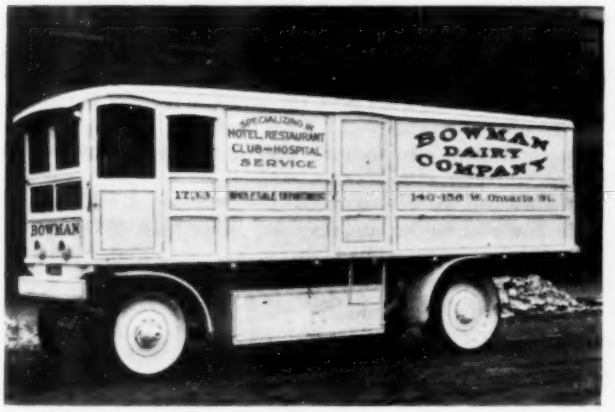


FIG. 3 ELECTRIC VEHICLE FOR WHOLESALE DELIVERY

4 *Garaging Cost.* The electric truck is no fire hazard in buildings. It can be garaged and charged inside of warehouses or manufacturing plants without affecting the insurance rate on the building or its contents. This means that enclosed loading platforms are often utilized for garaging, and the expense of separate garage buildings is saved.

5 *Cost of Current.* Current for charging the storage batteries is usually consumed on off-peak night rates, and current so obtained is very cheap. At 1 cent per kw-hr., current costs will vary from ½ cent per mile on light-duty electrics to a maximum of 2 cents per mile on heavy-duty electrics. Usually the cost of current plus the depreciation charge for batteries will be less than the cost for gas and oil on a corresponding size of gas truck doing the same amount of work.

6 *Fewer Accidents.* The underwriters' preferential rate on electric-truck insurance is based on actual experience of electric-truck users in the matter of few accidents. Aside from the saving in truck insurance premiums, freedom from accidents means reduced workmen's compensation, reduced maintenance, reduced time of equipment out of service, and reduced pieces of extra equipment.

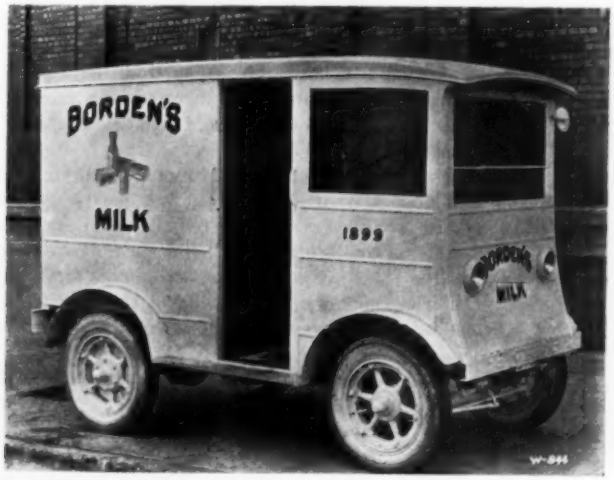


FIG. 4 ELECTRIC VEHICLE FOR "NOISELESS MILK" DELIVERY

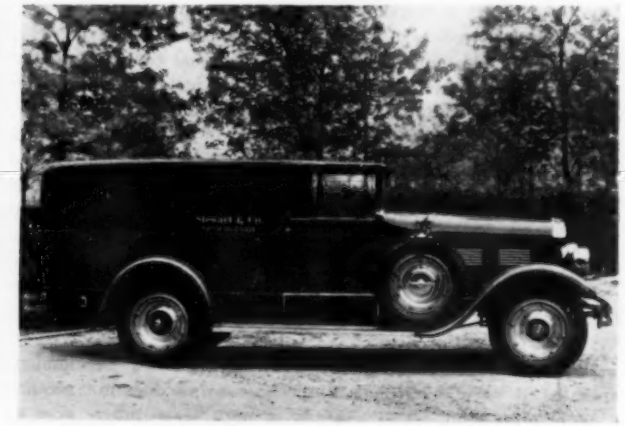


FIG. 5 ELECTRIC PACKAGE VAN WITH THE SMARTNESS OF GASOLINE-CAR APPEARANCE

7 *Dependability.* Dependability is essential for economical route operation. Dependability, also, demands the ability to operate under extremes of weather conditions. Aside from accident, it is extremely rare for an electric to be off its route, except for painting. This company has a large number of trucks operating which have not missed a day off their routes from one year's end to the next.

8 *Power.* From the standpoint of power, the electric is much more powerful than is a corresponding size of gas truck. Electrics will pull up grades or plow through snow where other equipment cannot operate. This great power does not come from a high-powered motor, but rather from the characteristics

of the motor. Straight-series motors are generally used in electric trucks. This type of motor develops its maximum torque at the stalling point of the motor. This is almost exactly the opposite of a gas engine, which develops its maximum torque only at high speed and therefore needs a gear reducer (transmission) to enable the engine to have enough speed to generate enough power to start a heavy load. Where the gasoline truck has to start its load through a transmission and by slipping a clutch, the electric motor, being always permanently connected with the rear wheels, starts the wheels directly the motor starts, and hence there is no shock on the mechanism.

9 *Few Moving Parts.* The motor armature, the gears, and the wheels are the only moving parts in the electric-truck drive. Add to this the steering gear and controller, and all the wearing parts have been named. The fact that there are few moving, wearing parts makes for low maintenance and high dependability.

10 *No Idling Mechanism.* When the electric truck is stopped, all parts are at rest. There is no idling motor consuming fuel and wearing itself out. Wear and tear on the electric occurs only when the truck is in motion and then to only a slight degree.

11 *Vibrationless.* The driving power, being a steady running rotating force rather than a reciprocating force, does not tend to set up vibration in the truck. The effect of this lack of vibration is evidenced in low maintenance and in the improved stamina of the driver.

12 *Noiseless.* The electric truck is absolutely noiseless in operation. For the many lines of business that specialize in night-time or early morning deliveries, this is a very valuable feature in promoting customers' good-will.

13 *Fast in Traffic.* Due to having no clutch or transmission to operate, the electric truck gets away faster from each stop and gets through congested traffic faster than any other vehicle. This time saved is worth money if intelligently used.

14 *Short Wheelbase.* The electric truck has, approximately, a 3-ft. shorter wheelbase than the conventional gas truck of the same size for any given length body. This feature saves garage space and makes for easier maneuvering and parking.

15 *Immunity to Weather.* The test of any equipment is not its fair-weather operation, but its operation in adverse weather conditions. Neither the hottest summer weather nor the coldest winter weather has any detrimental effect on the electric truck. The electric can be left out in below-zero weather for hours with no freezing or injury to any part. This immunity to weather conditions works for more dependable operation and does away with all expenses caused to other equipment by winter operation.

16 *Operating Temperature.* The electric-truck mechanism operates at normal outdoor temperatures and does not require a cooling medium. The absence of high temperature goes to prolong the life of the equipment.

17 *Sanitation.* The electric truck is clean and sanitary. There are no odors or fumes—an important consideration, particularly in the delivery of food products, clothing, and other mechanism. The drivers can easily keep themselves neat and will always convey to customers the impression of scrupulous cleanliness which their employers want customers to have.

18 *Simplicity of Operation.* No special skill is required to operate the electric truck other than to steer the vehicle. The speed of the vehicle is controlled by one handle operating a controller, which regulates the flow current from the battery to the motor. Because a skilled operator is not necessary, route men, who are usually salesmen, can be selected for their selling ability rather than their truck-operating ability. This means better route men and more sales for the owner.

19 *Driver Satisfaction.* The modern electric-truck driver is a satisfied driver. Not being subjected to excess noise, vibration, or wear and tear on their nerves due to high speed; not being called upon to tinker with complicated dirty mechanisms; being able to keep clean; not being worried about the performance of their truck—all have a decided bearing on the driver morale and driver turnover. Any reduction in driver-salesman turnover is a big saving to the owner.

20 *Special Designs.* Due to the electric units being so self-contained and simple in design, the electric truck lends itself readily to special designs to fit any type of business. These special designs result in savings beyond that possible with conventional-design vehicles.

21 *Advertising Value.* The electric will maintain its new appearance over its practical life as compared to the very short time a gas truck will retain its new appearance. This is due to the lack of vibration and racking due to high speed; also, to the absence of gas and oil spray attendant on gas-truck operations. On the street, clean, well-painted, and noiseless, it creates an impression of confidence for the company whose name it bears, in the minds of people who see it. Being continually on the move, the electric truck is a better advertising medium than a billboard on a boulevard, and this advertising value is worth a great deal to its owner in establishing prestige.

22 *Comparison of Operating Costs of Electric Trucks Versus Gasoline Trucks.* In their general uses, no direct comparisons are usually possible. The gasoline truck is generally conceded to be very expensive to maintain in short-haul work with a high number of stops per mile, due to the wear and tear of starting and stopping. This high-maintenance cost for multistop work has resulted in many concerns still using horses because of their objection of paying a high first cost for electrics. On the other hand, the electric does not compete with the gasoline truck in long-haul work. In general, it will be found true that the electric truck, properly applied to its work, will be the most economical means of transporting merchandise as compared to all other types of street equipment, and as compared to gasoline-truck costs in the electric-truck field, the saving in favor of the electric will be always greater than 25 per cent.

In conclusion, electric-truck operation may be summed up in one sentence, as follows:

The electric truck, immune to the extremes of cold or heat, more powerful for its size than any other type of equipment, easily controlled, sturdily built, with a simplified mechanism of few moving parts, avoids costly maintenance, practically never wears out, keeps merchandise and material flowing smoothly on schedule time, and effects important savings for its owner.

Economics of Highway Trailers and Semi-Trailers

By W. G. RETZLAFF,[1] DETROIT, MICH.

THE past few years has been an extensive development in motorized freight transportation. Traffic men have recognized the motor truck as one of their best tools in the handling of freight. In the minds of many, there exists the thought that the truck may some day displace the railroad, especially in the shorter hauls not exceeding a 300-mile radius.

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[1] Manager, Transportation Engineering Department, Fruehauf Trailer Company. Assoc-Mem. A.S.M.E.

Contributed by the Materials Handling Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

TABLE 1 AVERAGE TRUCK FIXED DAILY CHARGES (IN DOLLARS)

Capacities	Ford		1½-ton, 6-cyl.		2-ton, 6-cyl.		2½-ton, 6-cyl.		3-ton, 6-cyl.		5-ton		7-ton	
	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body
Interest	0.094	0.103	0.15	0.166	0.235	0.297	0.388	0.45	0.41	0.47	0.66	0.725	0.775	0.84
Fire and theft insurance	0.02	0.022	0.031	0.038	0.05	0.063	0.083	0.096	0.087	0.10	0.14	0.15	0.165	0.18
Property damage liability (5 and 10)	0.16	0.16	0.16	0.16	0.26	0.26	0.26	0.26	0.26	0.26	0.36	0.36	0.36	0.36
Garage	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.75	0.50	0.75	0.75	1.00	0.75	1.00
License	0.080	0.085	0.088	0.10	0.17	0.25	0.26	0.30	0.26	0.33	0.40	0.46	0.42	0.54
Wages	5.00	5.00	5.00	5.00	5.50	5.50	5.50	5.50	5.50	5.50	6.00	6.00	6.50	6.50
Totals (per day)	5.85	5.86	5.93	5.96	6.72	6.87	7.00	7.36	7.02	7.41	8.31	8.70	8.97	9.42
Total investment	756.00	821.00	1175	1325	1875	2375	3100	3600	3250	3750	5300	5800	6200	6700

This has resulted in the establishment of corporations to haul freight between large cities. The truck companies, seeing the possibilities, have designed trucks or tractors especially adapted for long-distance freight hauling.

Legislation has followed, and today practically every state has laws regulating the length, width, speed, and weight of vehicles on the highway.

As the motor-transport business continued to grow, some men specialized in this field. Later, these men became known as transportation engineers. And today we find that practically every large truck and trailer company has established a transportation engineering department whose chief function is to determine the most economical method of handling any particular commodity using truck-tractors with trailers.

Surveys are made, and from the data collected, the most eco-

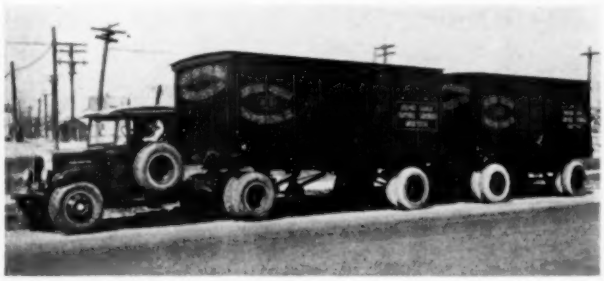


FIG. 1 SEMI-TRAILER AND FOUR-WHEEL TRAILER HAULING ABOUT 20 TONS PAY LOAD ON MICHIGAN HIGHWAYS

(The Southern Michigan Transportation Company, formerly the Michigan United Electric Railway, has turned loss into profit by eliminating electric freight cars and substituting 83 trailers.)



FIG. 2 SOUTHWESTERN TRANSPORTATION COMPANY HAULING THROUGH THE SOUTHWEST FOR THE COTTON BELT RAILROAD

(They are using a large fleet of semi-trailers and four-wheel trailers.)

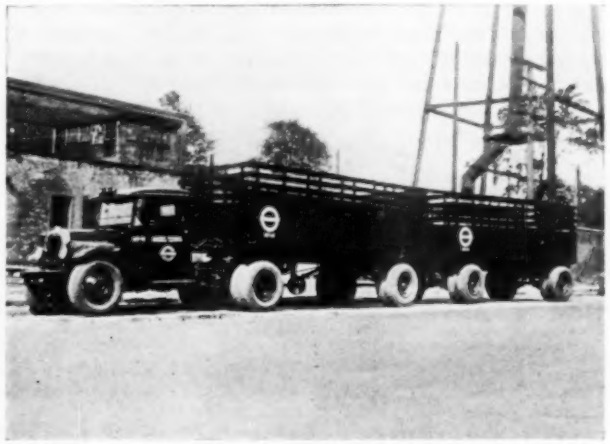


FIG. 3 EASTERN MICHIGAN TRUCKING COMPANY, FORMERLY THE DETROIT UNITED RAILWAY

(They are eliminating electric cars and substituting the tractor-trailer method of freight hauling.)

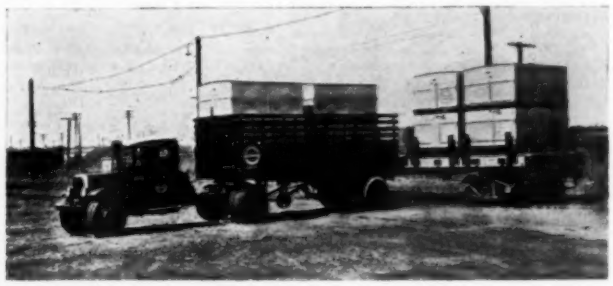


FIG. 4 EASTERN MICHIGAN TRANSPORTATION COMPANY SYSTEM USING THE CONTAINER METHOD

(The electric railway hauls the containers between the points far apart, and the containers are then shifted to the trailers for pick-up and delivery. These containers weigh about 2500 lb. apiece, but new design will not exceed 1500 lb. The capacity of each container is about 5 tons.)

TABLE 2 AVERAGE TRUCK VARIABLE CHARGES (IN DOLLARS)

Capacities	Ford		1½-ton, 6-cyl.		2-ton, 6-cyl.		2½-ton, 6-cyl.		3-ton, 6-cyl.		5-ton		7-ton	
	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body	Tractor truck	Truck and body
Gasoline	0.022	0.022	0.022	0.022	0.025	0.025	0.028	0.028	0.033	0.033	0.04	0.04	0.066	0.066
Lubricants	0.01	0.01	0.01	0.01	0.0125	0.0125	0.016	0.016	0.02	0.02	0.025	0.025	0.028	0.028
Tires, 20,000 pneumatic, 10,000 solid	0.009	0.009	0.009	0.009	0.021	0.021	0.021	0.021	0.03	0.03	0.031S	0.031S	0.04S	0.04S
Based on 100,000 miles depreciation	0.005	0.006	0.009	0.01	0.0144	0.0195	0.026	0.0316	0.027	0.0314	0.10	0.110	0.116	0.126
Maintenance	0.012	0.012	0.012	0.012	0.015	0.015	0.02	0.02	0.035	0.035	0.05	0.05	0.06	0.06
Total per mile	0.058	0.059	0.062	0.063	0.0879	0.0930	0.111	0.1166	0.145	0.1494	0.2465	0.2565	0.315	0.325

Tractor includes chassis and cab only. Truck and body includes cab and body value, about $500 on 2-ton and up.

To obtain total daily operating cost for tractor-truck or for a truck with a body, multiply the variable charges per mile by the number of miles traveled per day and add the fixed charges per day. No overhead is included.

nomical vehicle and the operating cost can be predetermined. The operators soon found that the single overloaded truck could not be operated on the highways on a paying basis. The tonnage was not large enough, and the cost was too great. Legislation also interfered.

Necessity being the mother of invention, the trailer was evolved and adopted. And today we find the motor truck used as a locomotive pulling trailers over the highway, hauling large loads cheaper than ever before.

Cost of Operation

The most important question that the transportation engineer must answer is, "What are the possible savings and how soon will the installation pay for itself?" To answer this it is first necessary to determine the approximate operating cost.

Data on truck-tractor and trailer operations have been compiled from the various surveys made and in collaboration with several of the truck companies. These have been placed in table form, and the approximate operating cost can be easily determined.

The operating costs have been divided into two divisions—first, the daily fixed charges, including such items as interest, insurance, garage, license, and wages; and second, the variable charges, including gasoline, lubricants, tires, depreciation, and maintenance. The variable charge is based on a mile of operation. The tables herewith contain all cost data to determine the total operating costs.

TABLE 3 SEMI-TRAILER DAILY FIXED CHARGES (IN DOLLARS)

Capacity	3-ton	5-ton	7½-ton	10-ton	15-ton
Model	961	373	379	381	345
Interest	0.0786	0.21	0.244	0.258	0.281
Fire and theft insurance	0.007	0.019	0.022	0.023	0.025
Property damage and liability (5 and 10), 10 per cent tractors	0.026	0.036	0.036	0.036	0.036
Garage	0.50	0.50	0.50	0.50	0.75
License	0.13	0.213	0.237	0.253	0.277
Wages	....	....	....	....	....
Totals (per day)	0.7416	0.978	1.039	1.070	1.369
Total investment (in grey lead), including fifth wheel, supports, and $500 body, except No. 961, where a $145 body is included	715	1910	2220	2345	2555
Tires	32 × 6 d.p.	34 × 7 d.p.	38 × 9.75 d.p.	36 × 12 s.	36 × 8 d.s.

TABLE 4 SEMI-TRAILER VARIABLE CHARGES (IN DOLLARS)

Model	961	373	379	381	345
Gasoline (additional used by truck)	0.006	0.007	0.008	0.01	0.016
Lubricants	0.003	0.0035	0.004	0.005	0.008
Tires (20,000 miles on pneumatic and 10,000 miles on solids	0.0076	0.0142	0.021	0.020	0.020
Depreciations (20,000 miles)	0.0028	0.008	0.0090	0.0107	0.0117
Maintenance	0.0014	0.004	0.0045	0.0053	0.0058
Total, per mile	0.0208	0.0307	0.0465	0.0510	0.0605

To obtain total daily operating cost for semi-trailer, multiply the variable per mile charges by the number of miles traveled per day and add to the daily fixed charge. No overhead is included.

TABLE 5 FOUR-WHEEL TRAILER DAILY FIXED CHARGES (IN DOLLARS)

Capacity	2-ton	3½-ton	5½-ton	8–10 ton
Model	A-431-R	B-461-R	B-473-R	B-479-R
Interest, 6%, life of 10 years	1.45	0.169	0.244	0.30
Insurance, fire and theft at $0.30 per $100	0.013	0.015	0.022	0.027
Insurance, personal liability and property damage, 5 and 10, 25 per cent of tractor	0.06	0.07	0.09	0.09
Garage	0.50	0.50	0.50	0.50
License	0.13	0.153	0.25	0.293
Wages	....	....	....	....
Totals per day	0.851	0.907	1.106	1.210
Total investment, R. and S. body, grey lead, b. k. brakes	1320	1535	2220	2720
Tires	32 × 6 d.p.	32 × 6 d.p.	34 × 7 d.p.	38 × 9.75 d.p.

TABLE 6 FOUR-WHEEL TRAILER VARIABLE CHARGES (IN DOLLARS)

Model	A-431-R	B-461-R	B-473-R	B-479-R
Gasoline (additional used by truck)	0.006	0.007	0.008	0.01
Lubricants	0.003	0.0035	0.004	0.005
Tires (20,000 miles on pneumatic and 10,000 on solids)	0.0076	0.0152	0.0285	0.042
Depreciation (200,000 miles, less tires)	0.0058	0.006	0.0082	0.0094
Maintenance	0.0029	0.003	0.0041	0.0047
Total, per mile	0.0253	0.0347	0.0528	0.0711

To obtain total daily operating cost for four-wheel trailer, multiply the variable per mile charge by the number of miles travelled per day and add to the daily fixed charge. No overhead is included.

For example, suppose that in the state of Ohio the engineer is recommending a heavy-duty 3½-ton tractor truck to pull a 7½-ton semi-trailer carrying 10 tons and a four-wheel trailer 7½-ton capacity also carrying 10 tons. Assume that it is a 100-mile run, or a 200-mile round trip. To determine the total cost add the fixed charge of the tractor truck, or $7.02 (Table 1), to that of the semi-trailer, or $1.039 (Table 3), plus that of the four-wheel trailer, which is $1.21 (Table 5), for a total of $9.27. The variable cost will be:

For the tractor (from Table 2)	$0.1450
For the semi-trailer (Table 4)	0.0465
For the four-wheel (Table 6)	0.0711
Total per mile	$0.2626

Total variable cost for 200 miles—$52.52.

The total operating cost will be:

Fixed charge	$ 9.27
Variable cost	52.52
To haul 20 tons	$61.79

or a cost of $3.09 per ton or $0.154 per cwt., which is actually less than the present railroad rate.

The saving in time is also a factor. In the truck-trailer, shipment from Detroit to Chicago, delivery is guaranteed within 24 hours, whereas railroad shipment requires three to four days.

Equipment to Recommend

The transportation engineer is faced with the various state laws and the physical limitations of the equipment. Is it best to recommend a long-wheelbase truck with a four-wheel trailer, or the tractor-truck with a semi-trailer, or the tractor-truck with a semi- and four-wheel trailer?

Generally speaking, the four-wheel trailer, although it carries the load equally distributed, is rather hard to handle in heavy traffic. From depot to depot and for long-distance hauls it serves its purpose.

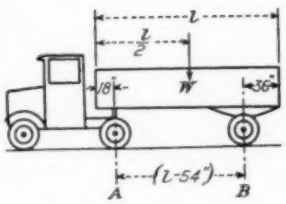
The semi-trailer, however, is easily handled in the most crowded traffic and will double the truck load because the weight is spread over two axles. However, the semi-trailer should be so constructed that the body overhangs in front of the tractor axle and throws about 45 per cent of the pay load on the tractor axle. This will give about the same gross load on the trailer and tractor tires and permit using the same size of tires all around.

Weight Distribution

To determine the weight distribution of a semi-trailer and tractor, note the illustration:

$$\text{Weight at } A = \left(\frac{\frac{l}{2} - 36 \text{ in.}}{l - 54 \text{ in.}}\right) W + (0.20)\, C + \text{weight of rear end of tractor}$$

$$\text{Weight at } B = \left(\frac{\frac{l}{2}L - 18 \text{ in.}}{l - 54 \text{ in.}}\right) W + (0.80)\, C$$



Let

l = length of trailer in inches

W = pay load plus weight of body

C = weight of chassis.

Length of Combination of Vehicles

Most states limit the operator to two trailers, and in some states only one trailer is permissible. The overall length of a combination of vehicles permitted varies in most states between 60 to 85 ft. The average tractor and semi-tractor will have an overall length of about 38 ft. If a four-wheel trailer is added behind the semi-trailer, the overall length becomes 56 ft.



Fig. 5 Universal Carloading & Distributing Company Delivering Containers From Railroad Yard to Consignee

(Each tractor-trailer can haul three containers, whereas the truck carries only two containers.)



Fig. 6 One of the Trailers Used in Shifting Freight Between Depots in Minneapolis and St. Paul

Axle Loads

Most states limit the gross load to 16,000 or 18,000 lb. per axle and a few to a 5000- or 6000-lb. wheel load. The value of the trailer can be readily seen. With an 18,000-lb. axle law, the semi-trailer could carry 36,000 lb. gross on the tractor rear axle and on the trailer axle. The four-wheel trailer can also weigh a gross of 36,000 lb. In a few states the total gross load is also limited; for example, in New Jersey the limit is 30,000 lb. gross and one trailer only.

Tires

When one considers that on every vehicle the average tire cost is about 2 cents per mile, the importance of this item is apparent. The pneumatic tire is gradually replacing the slow-speed solid tire, and there is hardly a doubt that in the near future the balloon tire will occupy the same position in the hauling of freight as it does today in the passenger-car field. Most operators must be cautioned that pneumatic tires cannot be overloaded in the same proportion as solid tires. The ratings of the tire manufacturers should be followed in all installations.



Fig. 7 Trailer Train as Used by the E. H. Scott Transportation Company

(They own a large fleet of Trailers and haul most of the freight for the Pennsylvania Railroad.)



Fig. 8 Trailers of the Middle States Transit Company, Owned by the Ohio Northern Electric Railway Company

(They are extending freight service beyond the track limits, using the trailer method. These units are duplicates of those used by the Southern Michigan and Eastern Michigan Transportation Companies, and the equipment is built to interchange with the Michigan companies.)

Truck Tractor

The old saying that a horse can pull more than it can carry is also true in modern truck transportation. On the average, a 5-ton semi-trailer calls for a $2^1/_2$-ton tractor or a 10-ton semi-trailer calls for a 5-ton tractor. In other words, the capacity of the tractor should be one-half of the rated capacity of the semi-trailer.

Trucks vary to a great extent in both the horsepower of the motor and in the rear-axle gear ratio. Both are very important, depending on the grades of the route, the total load, and the speed.

Experiments have shown that 12 lb. of rim pull at the tractor wheels will pull 1000 lb. gross weight on a level paved road, using a rubber-tired Timken-bearing-equipped vehicle. For average operating conditions, a 2 per cent grade is assumed. In other words, it requires 32 lb. of rim pull to move 1000 lb. gross weight on a 2 per cent grade.

Knowing the torque developed by the engine (generally given

by all truck manufactures), the rim pull can be easily determined from the following formula:

$$RP = \frac{T \times 12 \times R \times E}{\frac{D}{2}}$$

Where

RP = Rim pull in pounds
T = Torque in foot-pounds
R = Rear-Axle gear Ratio
E = Mechanical efficiency about 90 per cent
D = Nominal Tire diameter

For example, take the G.M.C. tractor T-60, about a $3^1/_2$-ton capacity, with 38×9.75 balloon tires and with a maximum axle-gear ratio of 12. The torque is given by their Engineering Department as 215 ft-lb. Substituting in the formula, this becomes

$$RP = \frac{215 \times 12 \times 12 \times 0.90}{\frac{38}{2}} = 1466.5 \text{ lb.}$$

On a 2 per cent grade it will move $1466.5/32 = 45.8 \times 1000$ lb. = 45,800 lb. gross in high gear.

As the tractor and trailer weight about 14,000 lb., the maximum pay load would be about 31,800 lb.

Speed

Knowing the governed speed of the motor, which in the foregoing example is about 2500 r.p.m., and the tire diameter and axle-gear ratio, the maximum speed can be easily calculated.

By changing the axle-gear ratio, of which every manufacturer provides several, the best compromise between pay load and speed can be arrived at.

Lowest Cost Freight Transportation

In the average industrial plant today the factory and the office have been organized and placed on a systematic basis by the modern mechanical and efficiency engineer. Unfortunately, most of the them stop their efforts at the shipping-room door. The Shipping Department, which handles all incoming and outgoing material, is generally regarded as a necessary evil—an overhead item of little account—and the operation and choice of equipment are left largely to the judgment of the shipping clerk. As a result, large savings are possible in almost every plant where a survey is made. It is not at all unusual to find an installation which will pay for itself in a year's operation.

The large corporations have awakened to this situation, and realizing the savings, they have appointed able executives in charge of their rolling equipment.

It is believed that the day of the heavy, slow-moving, solid-tired, inefficient truck is past. It is being rapidly replaced by the more efficient, high-speed six-cylinder pneumatic-tired truck manufactured on a quantity basis and adopted from the passenger-car field. This light truck, used as a tractor and coupled with a semi-trailer, is ideal for industrial and city work. In Table 7 a comparison is made between a 3-ton truck and a good six-cylinder, $1^1/_2$-ton tractor with a 3-ton semi-trailer.

TABLE 7 COST COMPARISON FOR 3-TON TO 5-TON LOADS

	Using a 3-ton truck	Using a $1^1/_2$ ton tractor with 3-ton semi-trailer	Savings in using semi-trailer
Maximum capacity	5 tons	5 tons	...
Daily fixed charges	$7.41	$6.67	$0.74
Variable operating cost, per mile	0.15	0.082	0.068
Total cost per 50-mile day	14.91	10.77	4.14
Total cost per 15,000-mile year	4473.00	3231.00	1242.00
Initial cost of investment	3750.00	1890.00	1860.00

Notice the savings of $1242 per year and that the investment of $1890 will pay for itself in about one and one-half years.

Another popular size for city work is the 5-to-$7^1/_2$-ton unit. In Table 8 a comparison is made between a 5-ton truck and a 5-ton semi-trailer coupled to a $2^1/_2$-ton tractor.

TABLE 8 COST COMPARISON FOR 5-TON TO $7^1/_2$-TON LOADS

	Using a good 5-ton truck	Using a good 6-cylinder, $2^1/_2$-ton tractor with a 5-ton trailer	Savings in using semi-trailer
Maximum capacity	$7^1/_2$ tons	$7^1/_2$ tons	...
Daily fixed charges	$8.70	$7.98	$0.72
Variable operating costs, per mile	0.2565	0.142	0.115
Total cost per 50-mile day	21.52	15.08	6.44
Total cost per 15,000-mile year	6456.00	4524.00	1932.00
Initial cost or investment	5800.00	5101.00	790.00
Additional equipment included	Cab and $500 body	$500 body with B. K. vacuum power brake	

Notice the savings of $1932 per year over the straight truck method. It might be added that these figures were actually proved by the Standard Oil Company and the National Refining Company, which have decided to replace all their 3-ton and 5-ton trucks with the lighter tractor and semi-trailer. These units operate on grades as high as 17 per cent.

Undoubtedly it is the cheapest freight transportation today.

MH-52-10

Placing Wet Concrete With Belt Conveyors

By E. L. BENSON,[1] AURORA, ILL.

In this paper the author tells of various construction jobs where belt conveyors have been used successfully for placing the wet concrete. Figures are given to show the economies of belt-conveyor use for such purposes, and the particular types that best meet specific conditions. There are a number of things that must be given consideration in the design of conveyors for handling wet concrete. The author tells how special conditions are met.

APPLICATION of belt conveyors to wet-concrete building brings to building construction the economies and efficiency of one of the oldest yet most reliable units in the material-handling field. The constant feed of the conveyors forces the men in forms to work faster and permits the mixer to be operated at top speed continuously.

Portable conveyors for this work must be light so that they can be moved easily, and at the same time be strong enough to withstand heavy loading. They must also be dependable, as the contractor's season is short and, consequently, it is necessary to work at peak load under severe usage for the entire season. All of these facts must be considered in designing suitable equipment. The practicability of using conveyors for handling wet concrete was realized early and the design of portable conveyors was changed to meet conditions peculiar to the handling of this material.

The first use to any extent of conveyors on a major project was to handle and place concrete on a branch-sewer job at Springfield, Ill., seven years ago. A portable mixer fed a portable conveyor direct, which placed the concrete in the forms. At this time the application was comparatively new and, consequently, was watched closely. But even at this early date, the concrete was poured successfully, cutting down the gang from 27 to 10 men, eliminating all wet-batch wheelers, three dry-batch wheelers, and all track layers.

Another early major project in which conveyors were used was the pouring of the Seventh Street Viaduct in Decatur, Ill. A portable mixer fed a 66-ft. portable conveyor which elevated the concrete, placing it into forms at a height of 34 ft. There were 60 pier bents in line about 40 ft. apart. The forms were set up just ahead of the mixer and conveyor. Consequently, these units moved from one form to the next without interruption. The reinforcing steel in the pier bents was only $^3/_4$ in. from the surface, which made a wet plastic mix desirable. A $1 : 1^1/_2 : 2$ mix, with 1-in. stone as the maximum, was used, giving the concrete a $5^1/_2$-in. slump; a pliable, flowing, easily worked mixture. The conveyor handled this mixture at an average angle of about 31 deg. with no trouble from spillage, and a finish of even texture was produced.

Similar equipment has been used for pouring open channels.



Fig. 1



Fig. 2

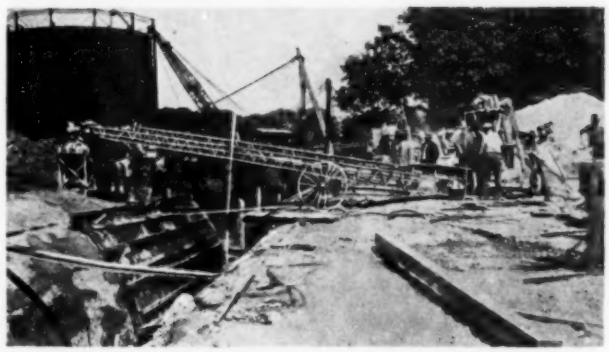


Fig. 3

FIGS. 1, 2, AND 3 PLACING CONCRETE ON LARGE SEWER AT SPRINGFIELD, ILLINOIS

After the excavation of dirt has been completed to grade, forms are placed ready to receive concrete. A portable mixer and a conveyor are used, both units traveling parallel to the right-of-way. On the Los Angeles flood-control project in Glendale,

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[1] Conveyor Division, Barber-Greene Co. Mr. Benson was born in Batavia, Ill., May, 1896. He entered the University of Illinois Civil Engineering College in 1915. He saw service for fifteen months overseas with the A.E.F. Mr. Benson received the B.S. degree in Civil Engineering from the University of Illinois in 1922. He entered employ of the Barber-Greene Company Engineering-Sales Department in 1923 and served as manager of the Field Service Department for two years, being placed in charge of the Conveyor and Special Applications Division Department in 1929.

Presented at the Third National Materials Handling Meeting, Chicago, Ill., March 5 to 7, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Cal., a 30-ft. portable conveyor and paver eliminated all wheelbarrows, cars, chutes, hoists, etc. Two units poured and placed 45 tons of concrete per hour. The conveyor carried the concrete from mixer to forms so rapidly that 6 to 8 men were kept busy on top of the form tamping. The work consisted of a concrete-lined channel 3400 ft. long, 47½ ft. wide, with 8 ft. perpendicular walls reinforced throughout. Concrete was poured at the rate of about 75 ft. of wall per hour and the entire job was completed in 32 working days.



FIG. 4 CONVEYOR AND MIXER USED ON CONSTRUCTION AT SPRINGFIELD, ILLINOIS



FIG. 5 PORTABLE CONVEYOR DELIVERING CONCRETE FOR SEVENTH AVENUE VIADUCT, DECATUR, ILLINOIS

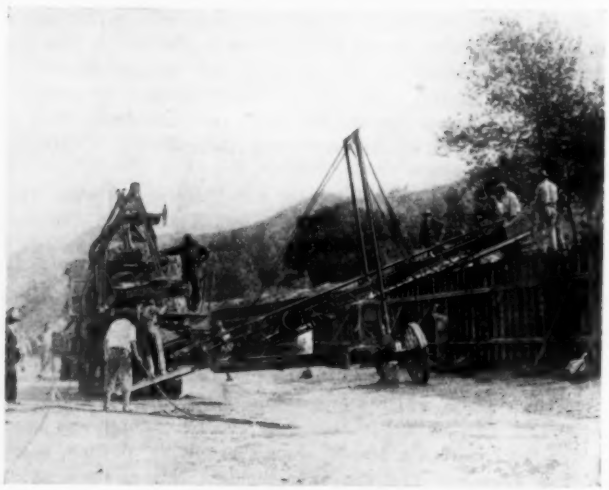


FIG. 6 PORTABLE CONVEYOR DELIVERING CONCRETE INTO SIDE-WALLS OF OPEN CHANNEL

Another type of construction, where conveyors have played an important part, is the stupendous and complicated sewage-disposal plants. These plants are becoming a necessity to the welfare and health of highly congested areas. An elaborate belt-conveyor system was installed for pouring the concrete in a large sewage-disposal plant located on the west side of Chicago. Conveyors were used to handle dry aggregates as well as concrete. There were 150,000 cu. yd. of concrete poured, and conveyors handled the major portion of this for pouring groups of units comprising skimming tanks, grit chambers, screens, and sludge-drying beds. A central mixing plant was used and concrete was fed direct from the mixer to a short conveyor which fed a permanent conveyor, 500 ft. long, equipped with self-propelled tripper. The permanent conveyor extended the entire length of the concreting area, feeding into shorter portable units at right angles which traveled over supporting runways and placed the concrete.

Conveyors also have been used extensively in placing concrete in retaining-wall forms on railroad work and deep-waterway projects. In this type of work the conveyors handle from 40 to 60 cu. yd. of concrete per hour, speeding up the jobs materially, due to the ease with which the units can be moved, which is essential for this type of construction.

There are two other fields of concrete construction which hardly have been touched upon; namely, the use of conveyors

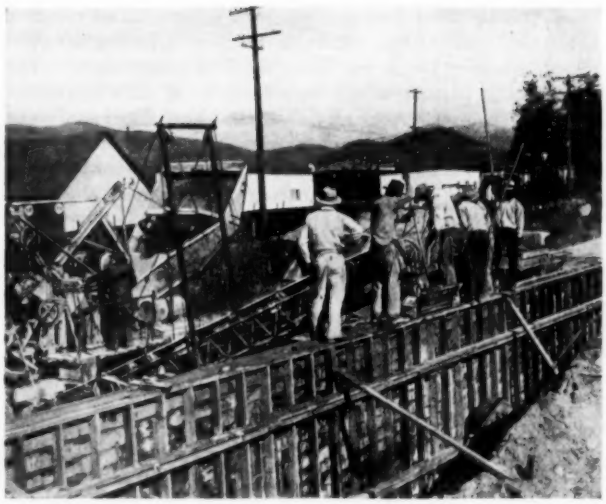


FIG. 7 DISCHARGE END OF CONVEYOR WITH MEN TAMPING CONCRETE

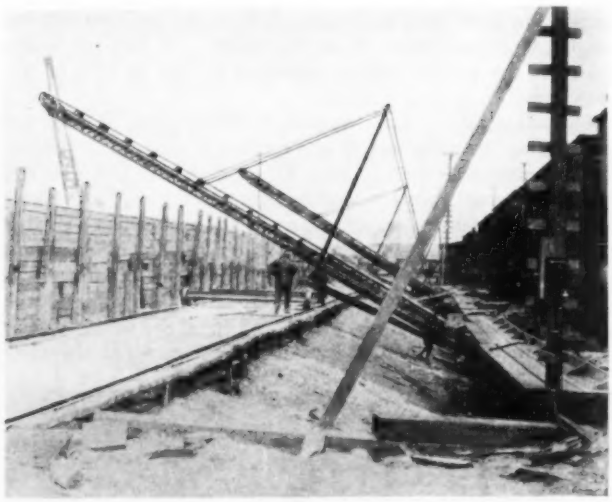


FIG. 8 PORTABLE CONVEYOR HANDLING DRY AGGREGATE FROM CARS TO STORAGE

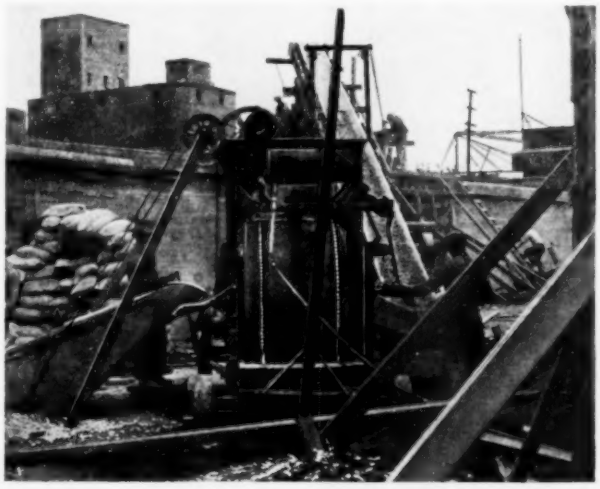


FIG. 9 BELT CONVEYOR POURING CONCRETE FOR RAILROAD RETAINING WALL



FIG. 10 PORTABLE CONVEYOR AND FORMS ON DEEP-WATERWAY PROJECT, JOLIET, ILLINOIS

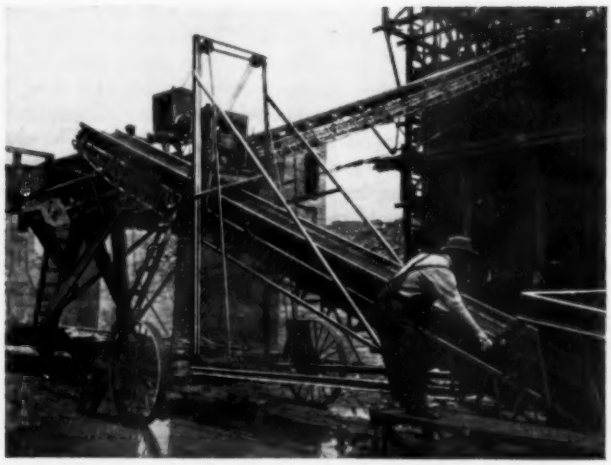


FIG. 11 TWO CONVEYORS DELIVERING CONCRETE TO FORMS

for pouring large dams such as are built in the far West and for pouring large buildings. As to the former, few data are available, but one project will be explained to give an idea of the procedure.

The Skagit River dam, located in Washington, is used for impounding the water supply of a number of cities in that state. It is approximately 1000 ft. long, 375 ft. high, and 170 ft. at the base. It is mass concrete construction, and the engineers specified that, in placing, the concrete could not be dropped a greater distance than 5 ft. This practically eliminated any other system than that of conveyors. Several towers were used with a skip hoist for elevating the concrete from the mixer. This part of the equipment is identical to the well-known spout and tower system. A boom was also supported by the tower from which two con-

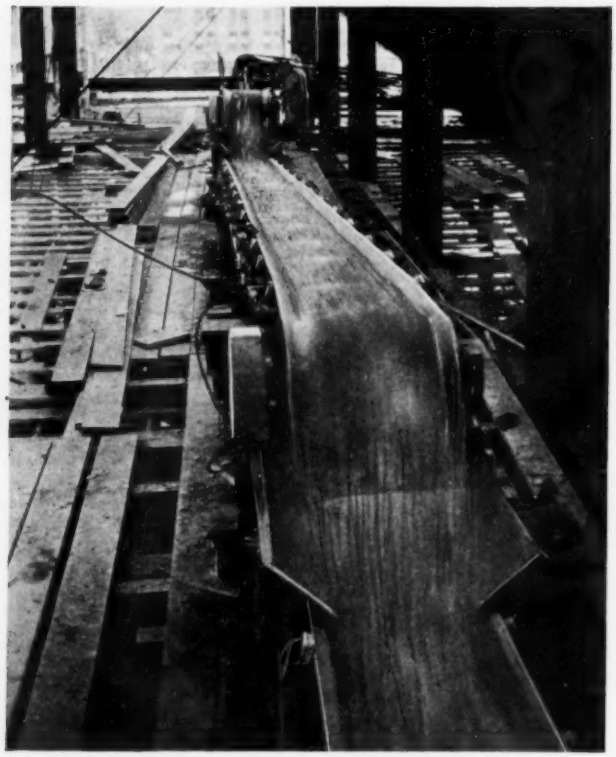


FIG. 12 DELIVERING CONCRETE FROM ONE MACHINE TO ANOTHER

veyors were suspended The boom unit, including the conveyors, was constructed so that it could be raised or lowered the entire height of the tower, and in addition the second conveyor was made to swivel so that a large area could be served.

On the new Merchandise Mart building, located in Chicago, which is the largest building of its kind in the world, 55 conveyors were used to handle the dry aggregates and wet concrete. The dry aggregate was brought in by battleship hopper-bottom cars. The tracks were located directly beneath the building itself, and the unloading section of track was excavated below so that the material flowed by gravity to the conveyor hoppers in pits. There were six belt conveyors used for unloading the aggregate, four on stone and two on sand. These machines unloaded 30 cars of material a day.

Two tunnel belt conveyors under the sand storage and two under the stone brought the material to two central mixing plants, one located at the side of the buiilding and one in the center. The material was then elevated by means of bucket elevators to the batching bins above the mixers.

Each mixing plant had two one-yard mixers. The concrete was elevated from the four mixers by four towers, having one-yard buckets, to a point two stories above the floor being poured. The short portable belt conveyors were located one floor above the floor being poured. Assuming that the third floor was being poured, the buckets in the towers raised the wet concrete to the fifth floor where it was discharged by a trip to a one-yard hopper. The hopper had a chute in the bottom which carried the mate-

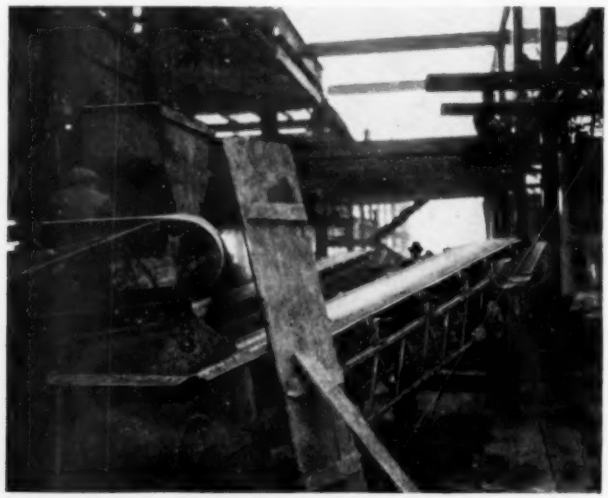


FIG. 13 STEEL IS ERECTED IMMEDIATELY ABOVE CONVEYORS, MAKING A VERY FLEXIBLE SYSTEM

rial down to the waiting conveyor on the fourth floor. Altogether, there were 44 portable conveyors handling concrete from this point. These units were 40 ft. long and each was mounted on rubber-tired castors. In distributing the concrete from the towers from 1 to 15 of these conveyors were used as required to reach the point above the spot being poured. The machines were moved about very easily, forming combinations, sometimes involving complicated crooks and turns.

Each conveyor was constructed in two units so as to facilitate easier handling when being hoisted from one floor to the next. The conveyors worked in series, and, as the placing of concrete progressed, the conveyors farthest from the hoisting towers were removed and put in position ready to go on the floor above.

To give some idea of the magnitude of the job and apparent successful application of conveyors for pouring the concrete, some figures will be given. The building was approximately 700 ft. long, 400 ft. wide and 18 stories high, with tower extending to 25 stories. There were 142,000 cu. yd. of concrete poured. To break this down further, so that it is more comprehensible, 6000 cars of gravel, 4000 cars of sand, and 1000 cars of cement constituted the material to pour this amount of concrete. About an acre per day of concrete was placed, and six days were required to complete a floor. The actual pouring of concrete started in March and was to continue through November but, due to a change in design, the job was held up 7 weeks, so that the pouring of concrete extended through December. When construction was temporarily stopped, the conveyors were used to handle debris of all kinds. This is important to a contractor, in that with conveyors he has equipment which is not limited in its usage.

From experience based on furnishing conveyors for handling wet concrete on jobs under varied conditions, it is found that there are a number of things which should be taken into consideration in the design of conveyors used for this purpose.

In general, when handling concrete and where conditions

permit, it is best to use a series of short units instead of long ones. Short units have a tendency to keep the concrete mixed and turned over as it discharges from one unit to the other. This also eliminates any tendency to segregate. In this connection it is important to space carriers as close as possible so that the belt will span the distance between carriers without sagging too much, due to the weight of the concrete.

Wet concrete is handled at angles varying from 12 to 36 deg. The angle at which concrete can be elevated is directly proportional to the slump of concrete and shape of the aggregate. The drier the concrete the greater the angle that the conveyor will handle the material. If the coarse aggregate is large and round, the angle cannot be as steep. Likewise, the capacity of a belt conveyor is affected by the slump of concrete, the shape of the aggregate, the angle of inclination, and belt width. The belt speed can be increased to 300 ft. per min. to increase the capacity. Beyond this speed, considerable slippage will occur with a consequent added wear on the belt. A belt is recommended not less than 24 in. wide because it has been noticed that anything less will cause spillage.

A rubber conveyor belt should be used which is not affected by water and in addition is easily cleaned. The best grade of belt is desirable, with at least five plies—or more, depending on the length of the conveyor. It should have a $^1/_8$-in. or $^3/_{16}$-in. extra rubber cover on the carrying side. The belt should also be heavy so as to decrease the sag between carriers as much as possible, yet it must be pliable so as to trough with the shape of the carriers to prevent spillage.

The power for driving the conveyor is directly proportional to the weight per cubic foot of the concrete, which, of course, is greater than that of either sand or gravel.

A machine to handle concrete must be light so that it can be moved readily and at the same time be constructed so that it will have strength to withstand the heavy loads which, in some cases, develop stresses of considerable magnitude. Conveyors of the portable type having Warren-type side trusses laterally braced seem to be the best suited. They combine maximum strength with minimum weight.

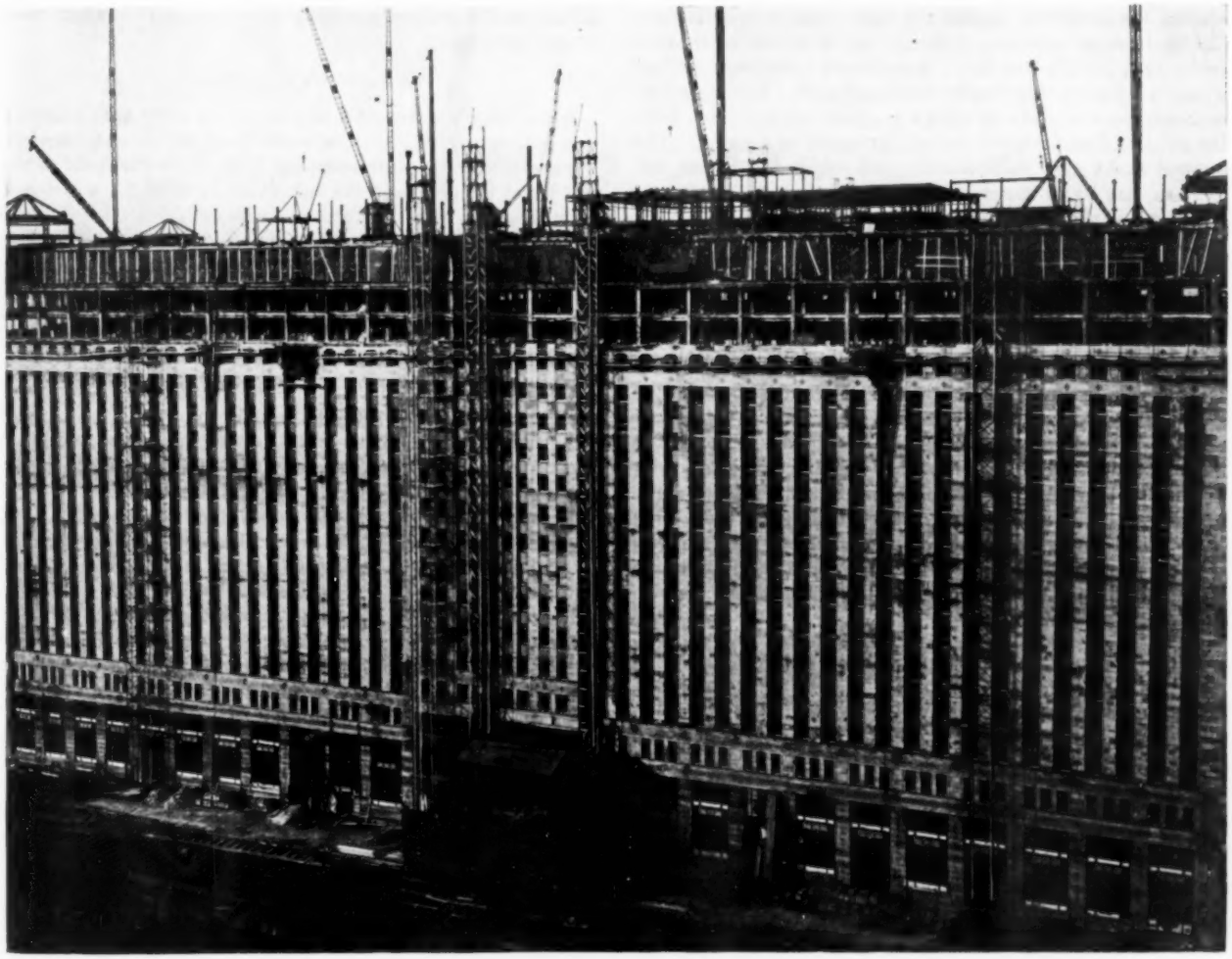


FIG. 14 PROGRESSIVE CONSTRUCTION OF BUILDING

Placing of rollers approximately 2 ft. apart eliminates the sag of the belt between rollers and, consequently, decreases the possibilities of segregation of aggregates. Where possible, it is desirable to use a feeding hopper for feeding the concrete onto the belt of the conveyor. Such a hopper assures a constant and uniform feed of the material on the belt, and, at the same time, starts the material off in the center of the belt which is desirable. The foot end of the conveyor should have a concentrating hopper about 9 in. wide so that a thin narrow ribbon of concrete is conveyed. The conveyor should be built as open as possible, expec-

ially at the foot end, where often there is spillage. This will make it easily accessible for cleaning. It is advisable to clean the conveyor thoroughly after each day's run. It is often desirable to coat the frame and all steel parts with oil which prevents concrete from setting on the frame and makes it easier to remove. An increased size for the tail pulley so as to eliminate undue flexure of the belt produces a saving in belt wear. It is also necessary to make this portion of the conveyor heavy and rugged to withstand the load of the wet concrete when dumped in the hopper. It is necessary to furnish rubber or wood scrapers at the discharge pulley located just under the pulley to clean the return run of the belt. On jobs where spillage is not of extreme importance, use is made of a counterweighted scraper, the weights keeping the scaper up against the belt. This scraper is satisfactory in most instances, although not as senstitive as other types. By this is meant that if once thrown away from the belt, it does not immediately replace itself against it. It is, therefore, necessary on some jobs to design a spring scraper which holds the scraping element up to the belt by means of a spring. This scraper works very satisfactorily and wipes the return belt clean so that very little material is carried back. The material to be used as the wiping medium also in some cases is important. Usually two or three thicknesses of belt would suffice while in other cases a 1 in. thickness of sponge rubber is furnished which does an exceedingly good job.

The conveyor as a medium for placing concrete has proved entirely satisfactory from a practical as well as economical standpoint. The length of the unit is limited only by conditions on the job or due to limitations of the drive. The action of the concrete while going over the rolls and the expansion and contraction of the belt between rollers keep it in continuous motion. This mixes the ingredients more thoroughly and, consequently, produces a better-mixed concrete than when it first leaves the mixer.

The principle of handling wet concrete is the same as that used for conveying any other material, using certain refinements in design to meet the conditions involved, bearing in mind that the machine will receive the severest usage and still must operate without break-downs.

Discussion

W. W. Burden.[2] Where freedom from shut-downs is as necessary as it is on engineering construction jobs, it would seem important to use special care in the selection or design of the troughing idlers on this type of portable conveyor unit. The value of dependable idlers and good bearings is important, expecially when conveyor speeds are increased. The bearings would necessarily have to be amply protected against the ingress of both dirt and moisture and should be designed so that lubrication is a simple operation and one that is easily handled by ordinary construction labor. It would also be interesting to check up on the actual depreciation of troughing idlers used in portable equipment of this type.

G. F. Pfeiffer.[3] To prevent spillage from return belts, revolving brushes and scrapers have been used, but complete spillage and a gradual gumming up of the parts has not been entirely prevented.

Author's Closure

In handling wet concrete, as well as any other bulk material, over belt conveyors, it is important to have well-designed carriers. For portable belts or semi-portable belts where the speed of the belt is not too great and the belt width 24 to 30 in., a cast-iron plain bearing with, preferably, pressure lubrication is best adapted from a practical and economic viewpoint. The bearings should be dust and grit proof to eliminate wear. The carriers should be the three-roll type, with rollers about 4 in. in diameter.

For high-speed belts, heavy loads, long conveyors, and where a saving in lubrication is important, a carrier having roller bearings and slightly larger diameter rollers is essential.

Protection against moisture in the bearings is of secondary importance, because on a well-designed conveyor there is practically no spillage, and the return-belt scraper wipes the return run of the belt dry; consequently, no water comes in contact with the carriers.

From experience it has developed that the squeegee type return-belt wiper is the most practical and gives perfect results. A double squeegee on spring-steel arms, fulcrumed at the end with adjusting screw in the middle of the spring arms, is believed to be the best type. It is positive in action, and the scraping elements are held in contact with the belt at all times. The scraping element made up of 4-in. seven-ply transmission belt is preferable. This has the required stiffness and flexibility to wipe the belt clean without injuring it.

[2] Anchor Steel and Eng. Co., Detroit, Mich.

[3] Moorman Mfg. Co., Quincy, Ill.

MH-52-11

Material Handling in Production of Pork Products

By A. W. DeVOUT,[1] CHICAGO, ILL.

This paper describes the various operations through which hogs pass from the buying pens in the stockyards until the various products are dressed, boxed, and placed in refrigerator cars ready for shipment. Handling equipment plays an important part in speeding up the operations, lowering costs, and doing away with heavy manual handling.



ONE OF THE pioneers in applying mass production to a continuous-line operation was the meat packer. His equipment was simple; an overhead rail and a shackle with which the carcass of the animal was hung by its hind feet. This shackle was pushed along the rail by a man with a long pole from operator to operator. A power-driven chain conveyor with a finger attachment soon eliminated this man, and this increased production and lowered the cost. Since that time there has been a steady increase in material-handling equipment of all kinds in every department of the meat-packing plant.

The packing industry is essentially opposite in procedure to many industries, such as the automotive, which assemble their many raw materials for the manufacture of one variety of product. The meat packer must dismember one raw material, the live stock, and produce almost innumerable varieties of goods. It is worthy of notice that these two differing types of industries use practically the same handling equipment, perhaps slightly altered to fit particular needs. In the packing industry this equipment has been so adapted and so coordinated with the rest of the plant that a practically continuous flow is maintained from the buying pens to the coolers and from the cutting rooms to the shipping docks.

The pork department, although but one of the many departments in a packing plant, offers the best illustration of coordination among the various types of handling equipment which are typical of the packing industry. The following description shows the flow of materials in the pork division of the Chicago plant of Swift & Co. This flow of materials is illustrated by the diagrammatic sketch, Fig. 1.

From the buying pens in the stockyards the hogs are driven up ramps to the top floor of the hog house. The elevating of live stock by means of ramps is economical, and hence gravity chutes and conveyors are extensively employed in later operations for transferring the product from floor to floor and department to department. On the top floor rest pens are provided where the hogs are washed and held for killing. Driven next to a pen in the dispatching room, one hind foot is shackled to the rim of a large revolving wheel which in turning raises the pendent hog to an overhead rail. The shackle engages with the overhead rail and automatically releases itself from the revolving wheel. By gravity the hog slides down the rail to the sticker, who skilfully severs the main veins and arteries of the neck. From the sticking rail the hogs then slide down to the bleeding rail. There ample time is allowed for bleeding. The hog is then allowed to drop into the scalding vat by a loosening of the shackle. The empty shackles are returned by a gravity rail to the shackling pen.

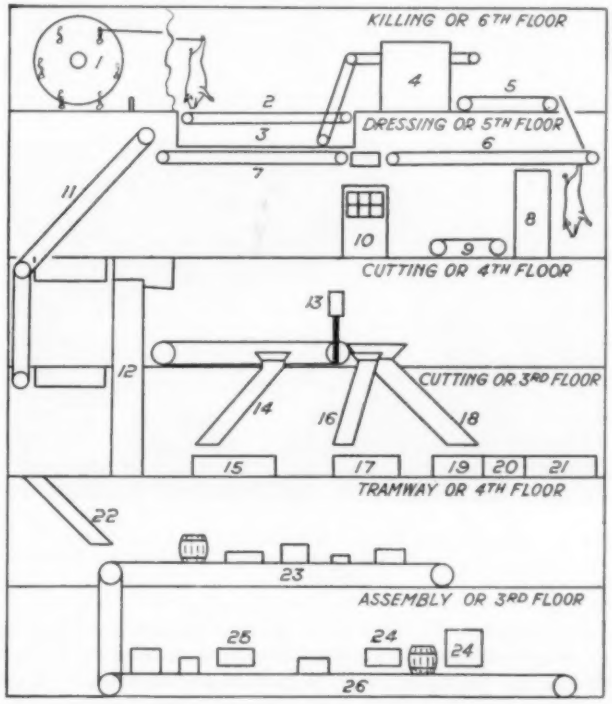


FIG. 1 DIAGRAMMATIC SKETCH OF HOG HOUSE

1	Shackle wheel	13	Shoulder chopper
2	Scalding-vat conveyor	14	Ham chute
3	Scalding vat	15	Ham-dressing table
4	Dehairing machine	16	Shoulder chute
5	Gambreling table	17	Shoulder-dressing table
6	First hog-dressing chain	18	Side chute
7	Second hog-dressing chain	19	Loin table
8	Automatic singer	20	Side-and-rib table
9	Viscera inspection table	21	Belly-trimming table
10	Scale house	22	Sliced-bacon table
11	Cooler conveyors	23	Shipping conveyor
12	Lift to bring hogs to cutting room	24	Fresh-pork chutes
		25	Smoked-meat chute
		26	Assembly conveyor

Next a hind-foot heel tendon of each hog is hooked on a slowly moving chain which carries the hog from one end to the other of

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Presented at the National Materials Handling Meeting, Chicago, Ill., March 5 to 7, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

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the scalding vat. This chain drag has displaced the old method of propelling the hogs through the tank by means of poles, and what is more important, insures that every hog remain in the scalding vat the proper length of time. This prevents over- or under-scalding. The purpose of scalding is to dissolve some of the protein substances which surround the hair in the hair follicles and make it possible to remove the hair easily.



FIG. 2 HOGS IN REST PENS

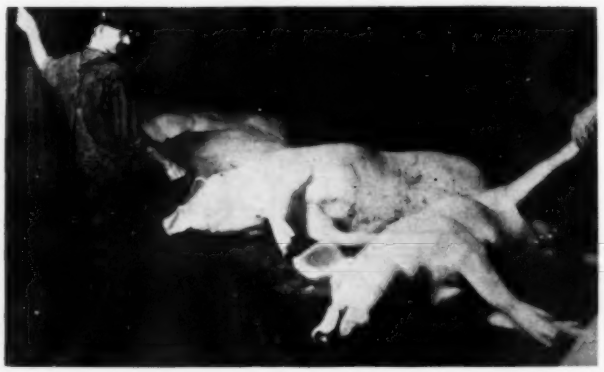


FIG. 3 GAMBRELING TABLE—A GAMBREL STICK IS INSERTED IN THE TENDONS OF THE HIND LEGS TO SPREAD THEM FOR THE DRESSING OPERATIONS

Another chain conveyor takes the hog through the dehairing machine from which in a few minutes the hog drops out on to a moving slat conveyor. Here a gambrel stick is inserted in the tendons of the hind legs to spread them for the dressing operations. The hog, fastened to the gambrel stick, is then hung on a trolley. From this point onward to the coolers the hog is carried on an overhead rail by this trolley. The hook which was used to bring the hog to the gambreling table, after removal, is returned by a rail to the front end of the scalding vat.

On the hog-dressing floor, directly above the rail, there travels a chain conveyor with a finger about every 27 in. These fingers engage each trolley so that the hogs proceed forward at regularly spaced intervals. The chain conveyors on the dressing floor are driven through variable-speed reducers which accommodate the killing grates. The fact that maximum capacity of this floor is 750 hogs per hour results in a chain-speed of approximately 27 ft. per min. The average hog capacity is about 400 per hour.

The hogs are admitted to the dressing operations by a man called the feeder, who also removes the hind toes. The hair not removed by the machine is removed by men that are stationed along the dressing line. However, to insure a perfect job, the hogs pass through a singeing machine and is then washed. Still being moved by the conveyor the hogs come to the header, who cut the heads free, yet leaving them to hang by a small piece of skin so that the government inspectors may examine the throat glands, marking and tagging those which do not meet the government requirements.

The carcass is next opened so that the viscera can be removed. The viscera on removal is placed on a moving table that is divided into pans. Each pan on this table is synchronized with a finger on the conveyor chain, so that the viscera proceeds forward at the same speed as does the hog from which it was removed. The purpose of this parallelism is to allow the government inspectors sufficient time to inspect the viscera and to tag those animals not up to federal specifications. Now, after evisceration, the hogs move along to scales at the end of the first conveyor chain. Here in drafts of five each the hogs are weighed. At this point the hogs are fed by a slightly inclined rail from the scales to the second chain conveyor. Such operations as splitting, removal of the head, leaf-lard removal,

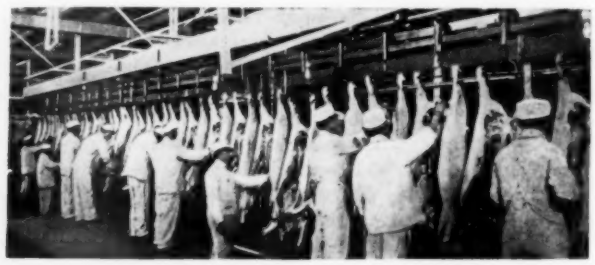


FIG. 4 HOG DRESSING—CHAIN CONVEYORS WITH FINGER ATTACHMENTS MOVE THE HOGS THROUGH THE DRESSING OPERATIONS

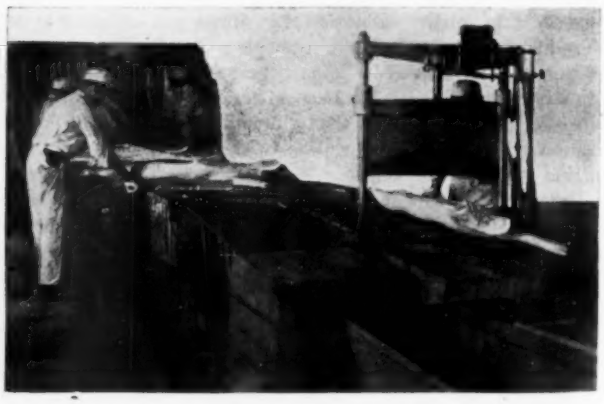


FIG. 5 REMOVING HAMS AND SHOULDERS FROM SIDES

and washing are completed on this second conveyor and the hog is ready for the coolers. Still remaining on the overhead rail, however, the hogs are conveyed by another series of chain conveyors to the coolers below. Each cooler is equipped with overhead rails so that the hogs may be spaced evenly throughout the rooms.

It is interesting to note that it requires only 25 min. for a hog to travel from the sticking pen to the coolers. After remaining in the coolers for 24 to 48 hr. the hogs are ready for cutting. They are moved from the coolers to a lift which brings them to the cutting floor. A chain conveyor pulls the hog across the moving slat conveyor and the tendons of the hind legs are cut,

dropping the hog on this moving table. The ham is scribed by a portable saw, and the next man deftly cuts off the ham, which drops by a chute to the ham-trimming table on the floor below. The next operation is the removal of the shoulder by means of a shoulder chopper similar to a guillotine. The shoulder is dropped by one chute and the side by another chute to the floor below.

As the sides reach the cutting table the loin is scribed with a portable electric saw and each side is slid along the table to a loin puller, who uses a drawknife for the operation. The loin is then passed to the trimming table, where it is trimmed and graded. It is then weighed and boxed on roller conveyors ready for delivery through a chute to the assembly conveyor. After the loin is pulled, the side is fed into a belly roller, which at the same time splits the side into a fat back and a belly. The fat back is trimmed and disappears down a chute to the floors below. The spareribs are removed from the belly by means of a drawknife, and the belly proceeds to the trimmers, antecedent to its removal to the curing cellars below.

On the same floor the hams which were removed on the floor above slide to the scene of the ham-trimming operations. Here a moving slat conveyor is used, and finally, at the end of the table,



Fig. 6 Interior of a Smoke House Showing Hams Hung on Special Trolleys

the hams are slid by a spiral chute conveyor to the grading room in the curing cellars.

It is worthy of notice at this point that the fresh product is boxed, weighed, and delivered on roller conveyors, and advanced to chutes which connect with the assembly conveyor on the third-floor cooler level.

Hams and bacon, after the curing process is completed, are taken from the cellar to soaking vats and chuted to slat-conveyor tables where they are prepared for smoking. As the product leaves the tables it is hung on special trolleys running on an overhead rail system that leads to the smokehouses. After the smoking, the trolleys are pushed to the smoked-meat hanging room there to await wrapping. The trolleys are dropped on a special lift to the wrapping room. Here is a series of belt conveyors and wrapping tables which discharge the wrapped product for packing into boxes. The boxes are carried forward by means of a belt-driven roller conveyor to a chute which discharges to the same assembly conveyor mentioned before.

In the packaging of sliced bacon the same familiar belt conveyor is used. The boxed product, ready for shipment, slides down a spiral chute to the head of the shipping conveyor on the tramway.

The assembly conveyor on the third-floor cooler level, as mentioned before, receives the fresh-pork packed orders and the smoked-meat packed orders through chutes. This conveyor, which is of the slat type, is connected by a gravity roller conveyor to another, a slat conveyor, which raises the packed goods to the tramway conveyor. At this point the boxed sliced-bacon slides on to the tramway conveyor.

Backed up against a rail which runs parallel to the shipping or tramway conveyor is a row of tractor trailors. In an aisle between this rail and the conveyor, the shippers stand removing from the conveyor the goods destined for their particular cars.



Fig. 7 Wrapping Hams and Bacon on a Table Equipped With a Belt Conveyor

Each man has assigned to him certain cars, and as each address on the package is marked with the car number, his work is quite simple. On this tramway the tractor trains are made up, and the tractors, now loaded, haul the product via the overhead tramways to a tractor train elevator which drops the entire train to a loading dock.

In this article only one assembly room is described, but other departments are also equipped with them, and they also are tied in with the tramway system. With the use of different assembly rooms in the various buildings, the overhead tramways, and five tractor train elevators, only a short space of time elapses before an order including items from many departments can be placed at the door of a refrigerator car.

Discussion

Nixon W. Elmer.[2] The paper covers a great deal of ground and, of course, could not go into detail. For instance, in the last part of the paper but a brief description is given of the efficient tractor trailer, assembly room, and train elevator system. Most of us do not appreciate how important a movement is involved. Figures for operation at the Armour plant may be of interest.

During 1929 there was shipped out of the Chicago packing plant one and one-half billion pounds of products and, on the average, each pound of this went for more than two journeys by tractor-trailer train. The cost per electric-tractor hour was almost exactly $1. However, before this is compared with the author's average figures, it should be noted that this includes the operator, the building maintenance, depreciation, and rent as well as maintenance and replacement of each tractor's individual share of over 4000 trailer trucks.

In analyzing individual tractor costs for both short and long hauls, it is interesting to find that they both worked out to almost the same cost, namely 1 cent per 1000 lb. per 100 ft.

[2] Engineer, Armour & Co., Union Stock Yards, Chicago, Ill.

While the figures are correct for departmental distribution of expense, they are, as abstract figures, not so favorable as they legitimately should be because of a plan used to encourage efficiency. The department is not charged for return loads. This makes the recorded tonnage too low and the ton-mile cost too high in like proportion, perhaps as much as 15 or 20 per cent.

MH-52-12

Hidden Costs in Materials Handling

By J. I. McCORMICK,[1] PITTSBURGH, PA.

A large variety of material-handling equipment and methods are used at the East Pittsburgh plant of the Westinghouse Electric and Manufacturing Company. The author tells how material is handled in different departments and the type of handling equipment found best suited to the requirements. He discusses various material-handling problems in a general way and tells of methods that are essential to reduce handling to a minimum.



INDUSTRY, in America today, holds its present position in the industrial world because it has adapted and applied mechanical conveyances, standardization, single-purpose machine tools, centralization of like products into one-plant set-ups where mass production has germinated, and grown plants that are a source of pride. With this progress ultimate customers are educated to accept a standard product, and engineering and sales policies are developed that have revolutionized industry. All this, along with the attitude of the workmen and their acceptance of the tools handed them, has made industry in America the envy of the world. Some of our keenest competitors in the world markets have adapted our approved methods. In Germany, Japan, or Italy today can be seen much of America's manufacturing procedures, and, in many instances, they have achieved higher success with our tools and methods than have we ourselves. Fundamentally, they start with an advantage in that their basic wage is some 50 per cent lower than ours. It behooves us if we wish to retain a balanced market here and abroad to dig deeper and better into those items that make up manufacturing costs.

Today no executive questions that a proportion of his unit costs is tied up in handling. The exact per cent varies in individual plants, but the author through association with some five plants, which have included automobile small parts and electrical apparatus, has accumulated sufficient data to say that approximately 80 per cent of the labor contents in unit costs is traceable to handling. Of this 80 per cent, 50 per cent is taken care of through operations on the floor, 12 per cent has to do with receiving, transferring to plant, transportation to the first operation, and packing and shipping; the remaining 18 per cent is a most fertile field for reducing unit costs, and one which presents problems that are answered and solved only after hard, diligent study.

A plant-planning engineer's job would be easy if all his layouts could be centered around quantity production, allowing mechanical handling and gaiting throughout, but unfortunately there are many plants, and many activities within plants, due to lack of production and certain inherent characteristics of the product itself, which do not lend themselves to any elaborate conception of materials handling and manufacturing processing, but reduced costs must be forthcoming under any system of manufacture. The cost trend must be established downward, and any plant of fair organization can lay out a new plant for a given product under ideal manufacturing conditions. When finished, this will be the last word in plant and manufacturing facilities. It takes a high-calibered plant organization, however, to take an old plant manned by 10- to 25-year old veterans, and swing them to new methods and turn out products at a unit cost comparable to the more fortunate competitor. This can be done, however, and within reasonable expenditures by judicious modernization.

The Westinghouse plant at East Pittsburgh is a diversified plant, manufacturing, in some form, a wide range of electrical apparatus. It covers approximately 5,000,000 sq. ft. of floor space scattered over a radius of eight miles, with six separate plants serving the main plant.

The foundry produces approximately 3,000,000 lb. of castings a month. The punch shop ships approximately 3,000,000 lb. of punched material. Shipments during 1929 averaged 11,200,000 lb. a month with an average of seven handling operations for each, which means that within the plant approximately 78,400,000 lb. are handled each month. Adding to this scrap ratio, there is coming in and handled through the plant approximately 42,336 tons. Manufacturing quantities average 50 to 100 pieces in the main items. This tonnage does not include coal, ashes, incoming maintenance material, or machine tools, which amount to approximately 70 cars a month.

Materials handling is a real problem to this company, and is placed by the management as of paramount importance throughout the East Pittsburgh plant. It is of such importance that two distinct departments have been formed for materials handling. The first is the transportation department, whose head C. A. Fike presented a paper at the spring meeting of the A.S.M.E. in 1928, at Pittsburgh. This department functions between plants and brings the bulk to the first operation on the floor, it also handles the semi-finished and finished product from department to department, but is not concerned with intra-departmental movement. The second is the plant-planning and layout department's function. This with the production department schedules and plans the material movement through to the shipping platform.

The objectives at East Pittsburgh through the materials-handling set-up and floor layout is to keep the work at one level, as it is found to cost $0.0036 for a floor lay-down and pick-up again to machine or bench level; also keeping the work in direct float and scheduled gait. Of course, these objectives are fundamentals in specialized plants, but are real problems when applied to the diversified plant.

It is planned to handle material mechanically as soon as it reaches the plant. In the punch shop the first machine is separated from the broad-gage track by a sliding door only, so that the sheet is unloaded directly to, and through the coating machine, ready for storage ahead of shearing. This eliminates one

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Presented at the Third National Meeting of the Materials Handling Division, Chicago Ill., March 5 to 7, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

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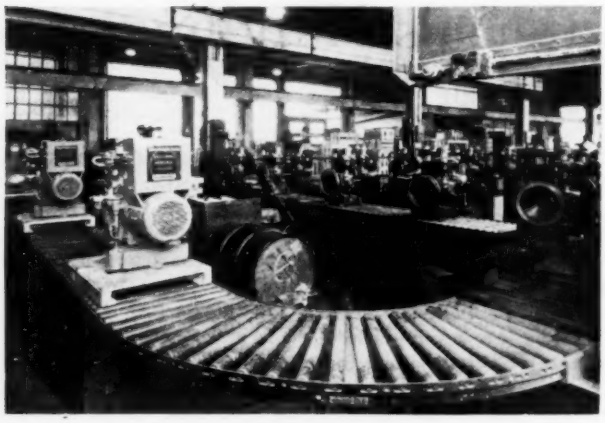


FIG. 1 GRAVITY CONVEYOR THROUGH SPRAY PAINTING AND SHIPPING DEPARTMENTS



FIG. 4 GRAVITY CONVEYOR MAINTAINS LEVEL AND FLOW

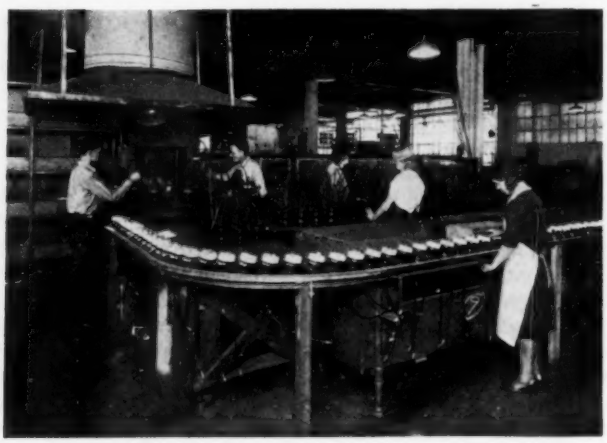


FIG. 2 STATIONARY SLIDE RAILS FOR PORCELAIN LIGHTNING ARRESTERS TO MAINTAIN MANUFACTURING LEVEL AND FLOW

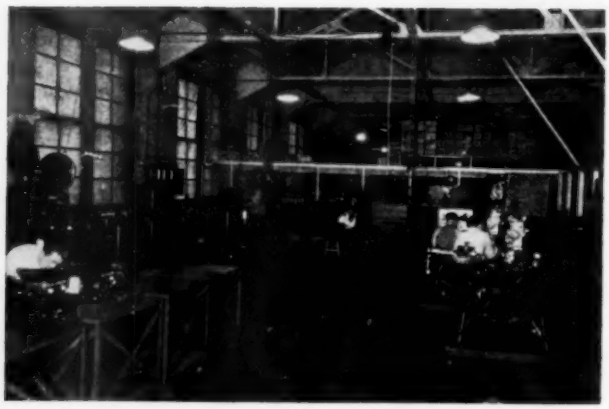


FIG. 5 ANOTHER EFFICIENT MEANS OF HANDLING IRREGULAR AND BULKY APPARATUS THROUGH ASSEMBLY, TESTING, AND SHIPPING

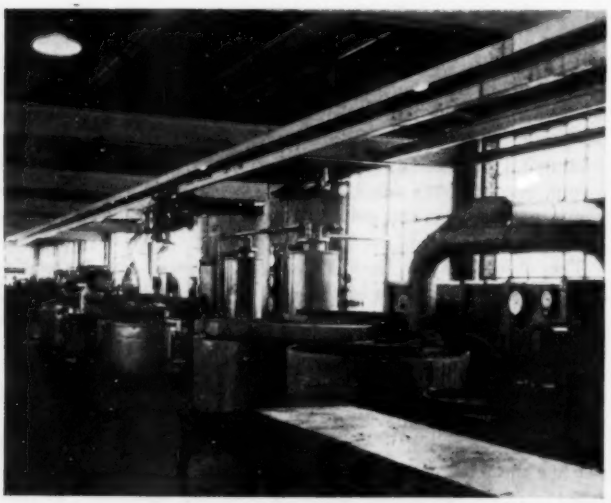


FIG. 3 COMBINATION OF MONORAIL, ELECTRIC HOIST, AND GRAVITY CONVEYOR HANDLING CONTAINERS 6 FT. IN DIAMETER



FIG. 6 HANDLING A VARIETY OF SMALL MOTORS

handling, or a movement of 3,000,000 lb. of sheet stock a month.

The product coming from the foundry is loaded into boxes that fit the inter-works transportation, either industrial gage or trailers. These boxes are placed at the run-off from the last cleaning operation. The inspector pushes the cleaned castings from his bench into the box, where they are piled on a broad-gage car for East Pittsburgh. The car is delivered at a point where an overhead crane will deposit the box of castings on an industrial car and lift truck or trailer for delivery to the first machine operation. The company is getting away, gradually, from in-



FIG. 7 MISCELLANEOUS CASTINGS SPRAY PAINTED WITH THE AID OF VERTICAL MOVEMENT OF TURN TABLE AND CONVEYOR FOR RETURN TO SECOND COAT

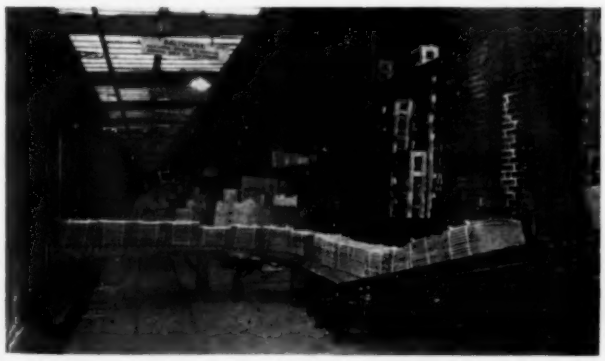


FIG. 8 GRAVITY AND POWER CONVEYOR MOVING CARTONS FROM CAR TO STORAGE

dustrial railway and lift trucks for the inter-works transportation by employing tractors and trailers. This means wider aisles, ramps, driveways, etc. throughout the plant. The economies that have been introduced more than justify the change-over. The saving is estimated at $33,000 a year under present plant loadings.

The correct answer to any handling problem is obtained through analysis of the factors involved in production:

1 Floor space available
2 Physical layout
3 Receipt and storage of raw material
4 Distribution of raw material and element parts
5 Classification of machine tools
6 Machine loading
7 Activity
8 Design
9 Separation of sub-assemblies
10 Separation of specials from standard
11 Scheduling
12 Complete assemblies
13 Processing
14 Inspection and testing
15 Physical properties
16 Storage of finished parts
17 Shipping
18 Investment
19 Economies.

Each of these factors usually presents different problems in handling, and when analyzed will give the desired method to use. Each factor must be treated separately and matched with the type of handling equipment best adapted to it. There are

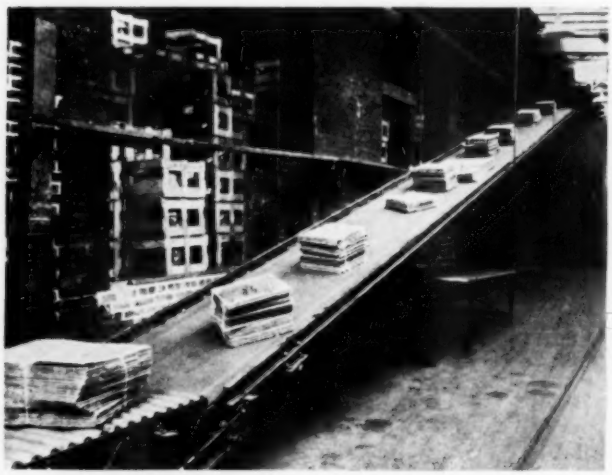


FIG. 9 CARTON CONVEYOR MOVING MATERIAL TO A SECOND LEVEL

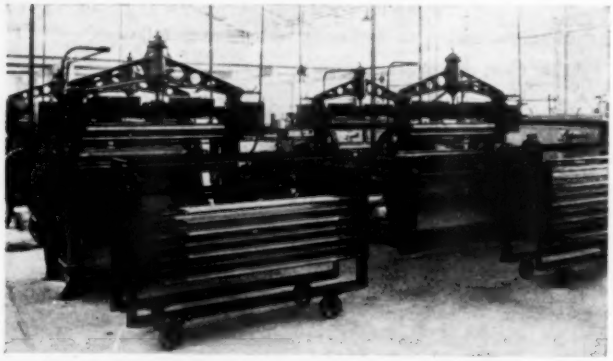


FIG. 10 BY PLACING MANDRELS ON TRUCKS FOR THE NEXT OPERATION OF BAKING, REHANDLING IS ELIMINATED

many factory managers and superintendents who still cannot see a place in their plant or department for mechanical-handling installations which they have seen elsewhere. It is not because these men are dull. Instruction on how to use equipment has been unmethodical and too fragmentary. The right application must be made of suitable, coordinated, material-handling equipment.

All have seen applications of handling equipment unsuitable, expensive, and nothing short of an "economical crime."

Those who have lived with reduced costs will recall that until recently handling was not considered in the analysis of those factors which made for profit or loss. The main points of consideration were material, major machine tools, tool fixtures, and design. Crude methods of machining, high cost of materials, and, above all, the design engineer, were criticized for the cumbersome designs with excessive weight and impractical tolerances and methods to obtain them. Engineering, and the art of manufacture, have advanced. Engineers have reduced weights and costs on large apparatus through fabrication, where every piece or order may be entirely different, involving no more waiting on patterns and castings.

All of the foregoing are factors in costs that are on the surface and which are obvious to those who look, but under the surface are hidden costs. These costs cannot be other than those of overhead, false economics, and handling.

Those factors which would give an algebraic expression for a handling constant, eliminating hidden costs, those intangible



FIG. 11 STATORS ARE HANDLED FROM MACHINE TO INSPECTOR BY CONVEYOR AND THEN TO INDUSTRIAL TRUCK

costs that are continually paring down profits and reducing the handling expression to its lowest terms are as follows:

A = Cost of handling from car to storage
B = Cost of handling from storage to first operation
C = Cost of handling from first operation, or manufacturing, to shipper.

Hidden factors involved:

X = Rehandling cost for "A"
Y = Rehandling cost for "B"
Z = Rehandling cost for "C"
W = Minimum handling costs

$$(A + B + C) + (X + Y + Z) = W$$

1 An outstanding hidden item difficult to measure is the handling cost of stock which does not have regular attendants; crews or individuals are shifted from other activities, periodically. Where one attendant is assigned to the entire section, modern handling facilities may not be considered justifiable, whereas, analysis may show that the operator is burdened with handling, and at times, several men are found helping the single attendant. Summarizing the time spent annually, it is found equivalent to two or more attendants. Therefore introduction of economics by modern handling facilities on surface costs are justified as full benefits will be realized only through reduced overhead where handling is an overhead factor.

2 *Broad-Gage Transportation.* This class of transportation, within and without, is most costly and should be avoided, if at all possible.

a Unloading Facilities for Raw Materials. Here is one place where rehandling must be eliminated and Babylonian methods abandoned. There are handling facilities on the market for individual problems.

b Where broad-gage transportation is essential, mixed cars

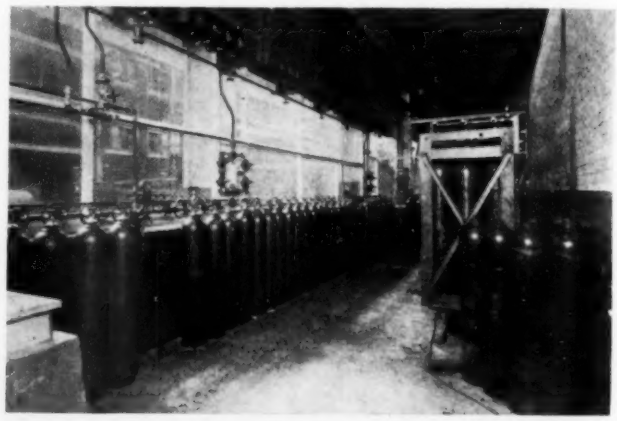


FIG. 12 HYDROGEN BOTTLES FOR FIELD USE ARE KEPT IN RACKS ON INDUSTRIAL CARS UNTIL FULLY CHARGED

should be avoided with material for north, east, west, and south parts of the shop.

c Tractors should be used for shifting in the yards, and power wenches for unloading positions, re-spotting empty and full cars to avoid idle-crew time and getting around Interstate Commerce full crews.

d Concrete should be used between broad-gage tracks to permit operation of tractors and trailers; particular attention should be paid to the area necessary for safe operation of tractors in bad weather.

With respect to broad-gage transportation, the time will be welcome when railroad companies will adopt standard cars to meet the handling problems. Possibly, a collapsible top for gondolas would be welcomed by those interested in steel, bar, sheet, pipe, and other materials. With the present box cars emptying costs are excessive.

3 *Power Plant.* This should be looked over, as there are innumerable handling problems, and ones which can go to the handling market for cure.

4 *Maintenance.* Here are involved many handling operations. The two most important ones are the "man" and "materials" movement. The man, or gang, should be given the right unit for conveying tools and materials to the job, preventing a pyramid of the "plumber's practice."

5 Handling also reverts back to the purchasing department. Its attention should be called to correct sizes required; eliminating handling of oversized stock and avoiding losses in scrap. Correct sized stock permits direct placement from car to floor, at the point of manufacture. This applies to sheet, sections, bar, and pipe stock.

6 *Scheduling.* There is considerable to be said about planning and scheduling raw material to the first operation on the floor, and keeping it in "float." Hardware should be located on the floor in the line of flow, thereby, eliminating rehandling.

7 *Manufacturing Level.* This term implies that materials

should be maintained at one level during the process of manufacture. It costs, as pointed out in a previous paragraph, much money to change levels, it increases man hours and investment in handling facilities. Modern machinery has played a great part in reducing the wear and tear on the human element, and correct methods of handling can do as much if given the same consideration and coordination of the shop forces. The operator should be kept at his position by moving materials to and from him by means of mechanical handling. The supervisor should have his set-up so arranged that he does the walking, and at a glance knows that the operator is kept in his position with work so scheduled that he has a visual measure of the day's production.

8 *Red Tape.* Red tape, or paper handling, is another source which, if not analyzed, will eat up reductions made through other sources. This set-up should run parallel with the manufacturing



FIG. 13 REDUCING HANDLING OF RESISTORS BY CONVEYORS—RAW MATERIAL IS KEPT IN CONTAINERS UNTIL USED

set-up; in other words, the clerk who is unproductive labor and a part of overhead should work in close connection with the paper work, following the material, and having it automatically returned to him so that he is rightly informed of the progress of the order. Systematic material routing is systematic paper routing and reduces to a minimum the necessary evil of stock chasers.

9 *Material Movement.* Movement through the manufacturing level should at all times be continuous. Skids should be used in connection with lift trucks, tractors, conveyors, portable tote-pan trucks, and racks. The skids should be designed with wheels so that they can be portable between immediate operations and still be handled by means of electric lift trucks or tractors for longer hauls. But, of all the handling methods and conveyances the simplest and most efficient method is termed "set-down" operation, or handling from operator to operator. Such set-ups have been accepted in preference to conveyors under certain circumstances.

Even with conveyor installation handling must be watched as often excessive handling on and off the conveyor, from operation to operation, is not shown in the operation itself. In a particular case there were 45 operators on a small unit weighing 10 lb. As this unit was handled off and on the belt each time, a close analysis revealed that a saving of 0.0003 hr. per operation could be effected or 0.0009 hr. per unit by direct passing. With the activity of 5000 units a day, the net savings were 45 hr., or the equivalent of $5^5/_8$ operators.

10 Inspectors should be kept moving.

11 *Processing.* This should be kept in flow and be timed so that refinishing is not necessary, nor wrap-up for protection.

12 Set-ups should be watched for break-ups. A production man may be "sandwiching in" his mistake, making rehandling necessary.

13 Handling must be tied-in so that the time-study department will have a clean-cut breakdown of handling operations. Intermediate handling operations should become a part of the operation line-up.

14 Americans are known as wasters both in industry and in their homes. They have been branded with the quotation that "their garbage cans would feed Chnia." Handling of materials must be done with the utmost conservation of materials and labor in mind. Excess material on castings should be watched. It costs to handle extra poundage both as castings and turnings. Salvage of scrap should be watched and that department centralized, transportation and physical handling should be saved allowing for improved control and studied work-over of scrap. Handling of hardware should be watched and standard containers used from receipt to the point of application, eliminating physical handling in and out of binnage, and in transportation. Processing should be watched. Centralizing will aid in obtaining manufacturing quantities to justify conveyorized set-ups, increase man output, machine loading, and improve the product.

15 The management of the Westinghouse Company has been most liberal in applying the incentive wage plan to activities heretofore not thought applicable, such as maintenance, plant transportation, storerooms, tool and die work, janitor service, and plant disposal of waste. Many of these activities, formerly



FIG. 14 SKIDS WITH REMOVABLE BOXES FOR WIDE-RANGE APPLICATION AND LONG-DISTANCE HANDLING BY USE OF ELECTRIC LIFT TRUCKS

considered indirect labor, are now considered direct labor and are written up as regular operations which are charged directly to the stock order. In the case of materials handling, the relation to productive labor is determined and the operation written up regularly. In costing, as has already been suggested, this item is regarded as direct labor and included in the cost of the product rather than in the overhead as an expense item.

Investment in handling equipment is an asset. Interest paid on unmoving stock is a liability. Decreased stock, under normal conditions, is the resultant of shorter manufacturing cycles, and the latter is a resultant of efficient handling methods, where 80 per cent manufacturing labor cost is the handling. There is no better way to cut costs than to simplify: (1) Designs, (2) tolerances, (3) tools, and (4) handling.

Discussion

W. W. BURDEN.[2] It would be interesting to have an analysis of the types and total footage of the various conveying systems in

[2] Anchor Steel and Eng. Co.

a plant like that of the Westinghouse at Pittsburgh and to know the trend as to type. Has there been found much opportunity in such a plant to substitute continuous movement of product and materials in place of intermittent movement, or are the operations so diversified that continuous movement in the main is not practicable? Likewise, it would be very interesting to learn the ratio of overhead handling to floor handling and the limitations of each.

MH-52-13

Conveyor Handling Methods of the Chicago Daily News

By MATTHEW W. POTTS,[1] NEW YORK, N. Y.

In this paper the author describes the conveyor handling system as installed in the plant of the Chicago Daily News. Continuous conveyors are used to handle rolls of paper from railroad cars and barges to the storage room, and then to the reel room. Conveyors are also used for handling stereotype plates to the press room, bundles of papers from the presses to the truck platforms, and mats from the makeup room to the stereotype room.

IN THE HANDLING of heavy loads and those of large dimensions it is the usual practice to use electric lift trucks, overhead monorail hoists, etc., and very seldom is it possible to install a continuous conveyor system for this class of commodity. The exception is the plant where the buildings or layout is designed around the handling system or with a definite handling system in mind.

The mechanical-handling installation at the Chicago Daily News uses continuous conveyors of unique design and application, and embodies a close cooperation between the design of the buildings and a definite layout of handling. Fig. 1 gives a general view of the complete conveyor installation for handling rolls of paper from railroad cars and barges to the roll storage room, then the reclaiming of these rolls and delivering to the reel room. It also shows a conveyor for handling stereotype plates to the press room and conveyors for handling bundles from the presses to the truck distributing platform, and a small installation for handling mats from the makeup room to the stereotype room.

It is seen from Fig. 1 that the railroad tracks are located in such a way that rolls can be taken from the railroad cars and put into storage without going through the first portion of the conveyor system. There is also a loading station on the ground floor with a turntable arrangement, so that rolls can be loaded to the elevator from trucks, or they can be unloaded from trucks direct to the reel room.

As much of the paper comes from mills located so that boat shipment can be made it was necessary to provide for quick unloading of these boats as they are not permitted to remain in the Chicago River over night. The boats carry approximately 1200 to 1500 rolls, and it is desirable to unload this in one day if possible so as to avoid the necessity of taking the boat out and bringing it back. This seems like a small matter, but the cost of the boat plus the lift-bridge charges, etc., make it a costly operation. When unloading from the boats the rolls are rolled onto the unloading dock and then are placed on the lowering skip. These rolls run in three sizes, the maximum being 40 in. in diameter, 6½ ft. long, and weigh 2200 lb. The skip is equipped with double carriers operating alternately, one ascending while the other descends, and this skip has capacity of 3 rolls per min. with a cable speed of 250 ft. per min. Fig. 2 shows the details of the skip and section *AA* gives a plan view of the unloading fingers for discharging to the apron conveyor in the tunnel. The conveyor and these fingers are shown in Fig. 3. On this operation the rolls are lowered approximately 46 ft.

After the rolls are discharged automatically to the apron con-

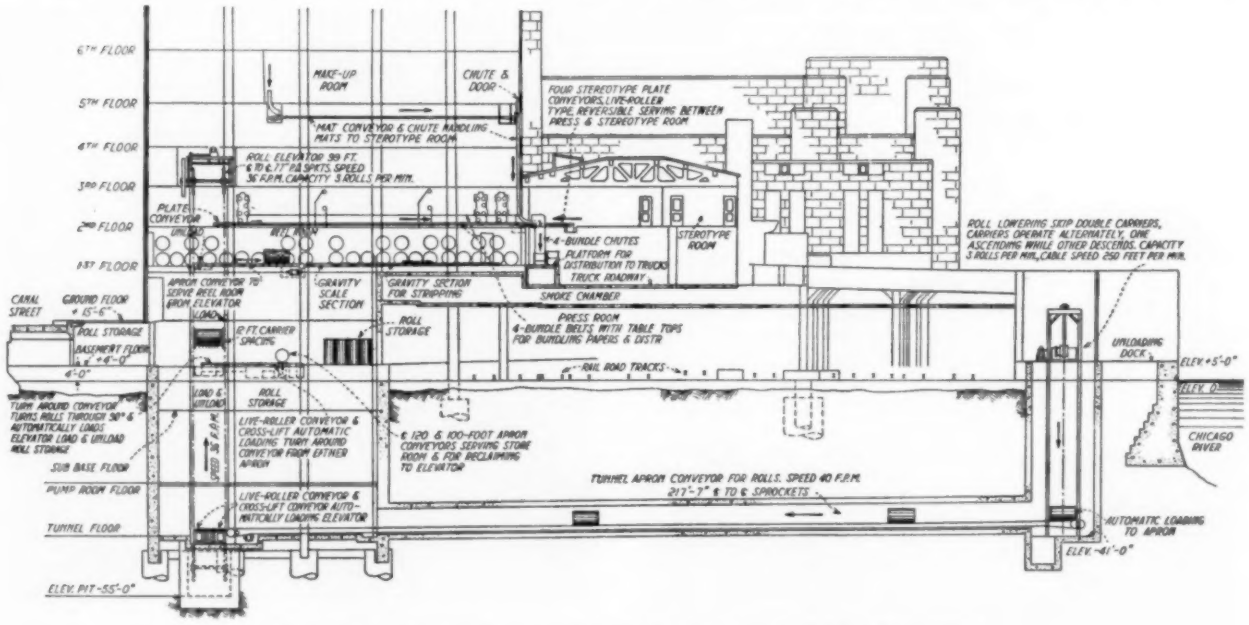


FIG. 1 SIDE ELEVATION SHOWING LOCATION OF CONVEYORS AND ELEVATORS

[1] Sales Engineer, Alvey Ferguson Co. Mem. A.S.M.E.

Presented at the Third National Meeting of the Materials Handling Division, Chicago, Ill., March 5 to 7, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

veyor they travel for approximately 220 ft. at a speed of 40 ft. per min. through a tunnel passing directly under the building. A view of the tunnel and the details of the conveyor are shown in Fig. 4.

It will be noted that the apron conveyor carries the rolls lengthwise, and when they discharge to the roll elevator they must be carried with the length across the carrier fingers so it is necessary to transfer from the tunnel apron to the loading fingers automatically, and at right angles. This is accomplished as shown in Fig. 5. This illustration shows the details of a definite automatic unloader and loading conveyor, and one which is unique in operation, being designed to meet a definite condition.

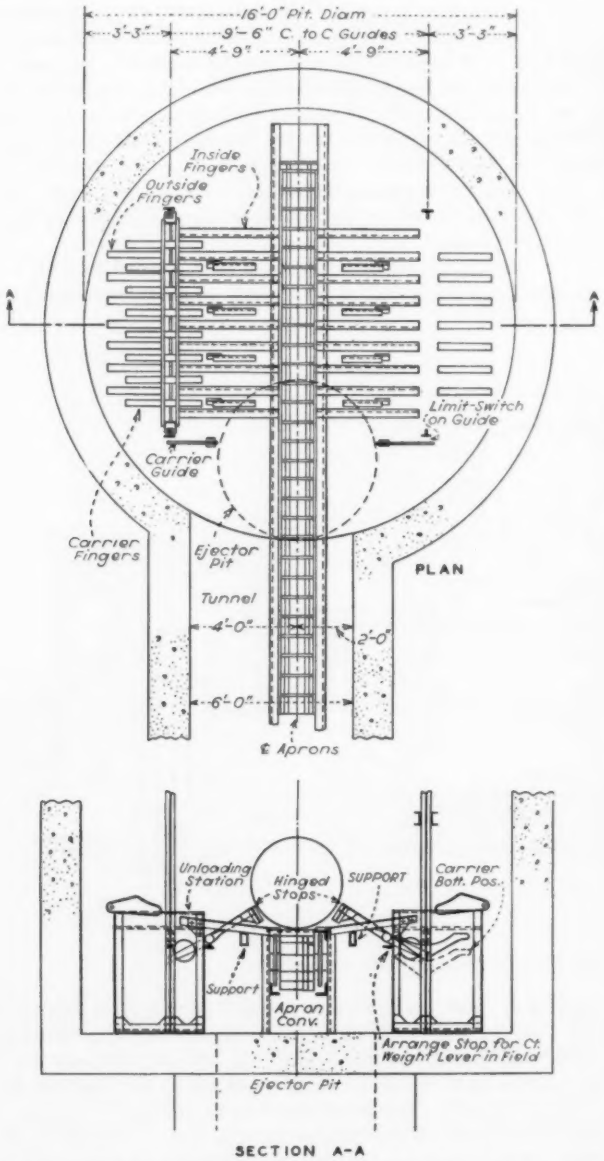


FIG. 2 DETAIL OF SKIP DISCHARGE SHOWING SAFETY FINGERS FOR STOPPING ROLL

As the roll leaves the tunnel apron it is fed onto a series of live rollers which are chain driven. The roll comes in contact with a

FIG. 5 DISCHARGE END OF TUNNEL CONVEYOR SHOWING DETAILS OF CROSS CONVEYOR FOR FEEDING TO VERTICAL PENDANT TYPE ELEVATOR

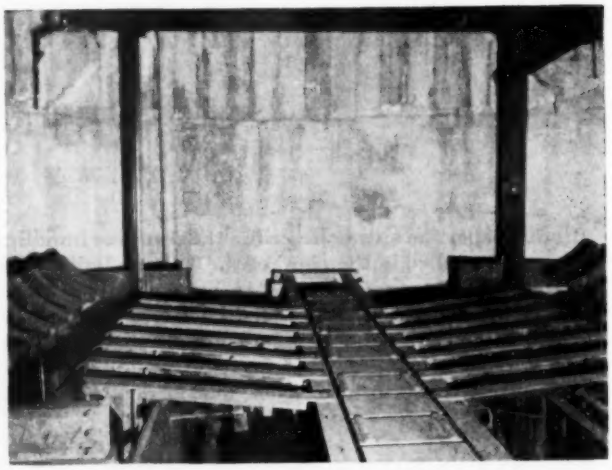
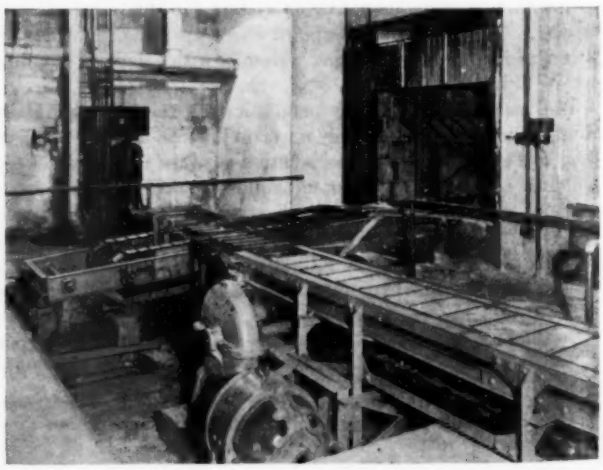


FIG. 3 VIEW OF SKIP UNLOADING FINGERS AND TUNNEL CONVEYOR FEED END



FIG. 4 LOOKING THROUGH TUNNEL SHOWING PART OF CONVEYOR WHICH IS APPROXIMATELY 218 FT. LONG



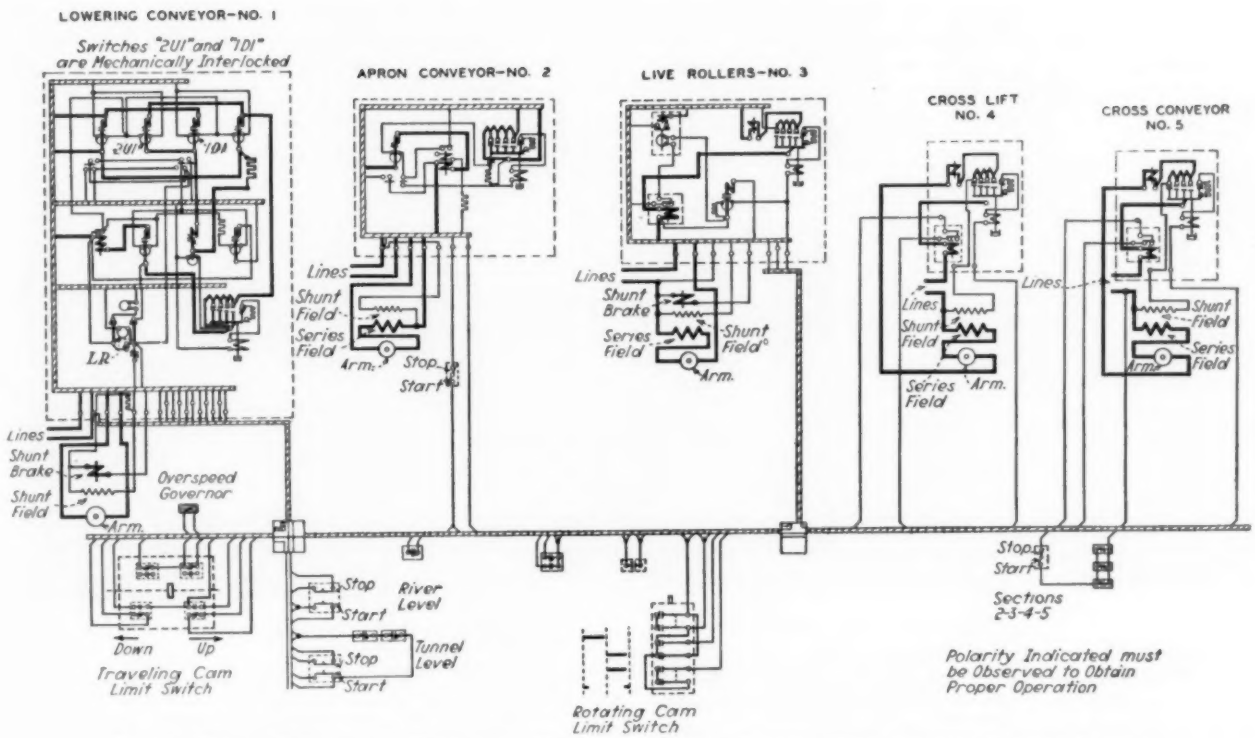


FIG. 6 WIRING DIAGRAM FOR CONTROL OF MOTORS ON TUNNEL CONVEYOR AND ADJACENT PART OF SYSTEM

bar which actuates the switch, stopping the live-roller conveyor and starting the motor on the lifting mechanism which raises the cross conveyor so as to take the roll of paper off the live rollers and at the same time propel it forward, discharging onto the loading fingers of the roll elevator. This seems in description

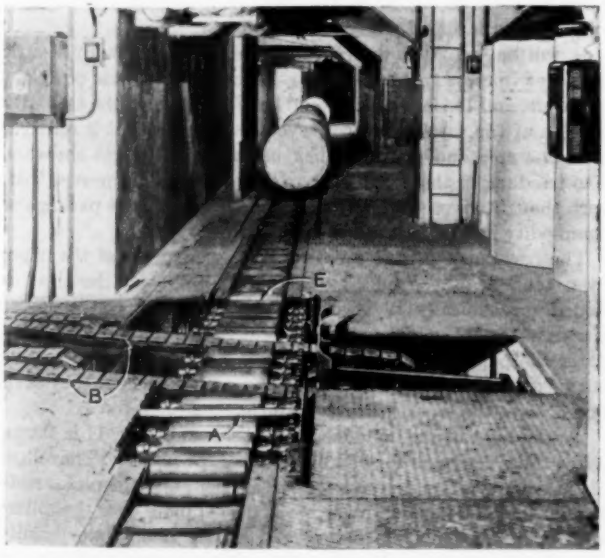


FIG. 7 TAKING ROLLS OUT OF STORAGE. NOTE HOW TRANSFER CONVEYOR IS DEPRESSED BELOW LIVE ROLLERS

to be a simple operation, but it reqiures considerable engineering to work out a device of this kind. Not only is it necessary to design the mechanical conveyors, but it is necessary to work out the exact location of the limit switches and the necessary cross bars, etc., for putting these switches in operation. Without going into details, the electric wiring diagram is shown with various circuits required for the lowering skip, the runnel apron, live-roll conveyor, cross conveyor, and cross-conveyor lifting mechanism. The roll elevator is approximately 100 ft. between center of sprockets and has a speed of 36 ft. per min. with a carrying capacity of 3 rolls per min.

As previously stated, on the rolls storage floor it is necessary to

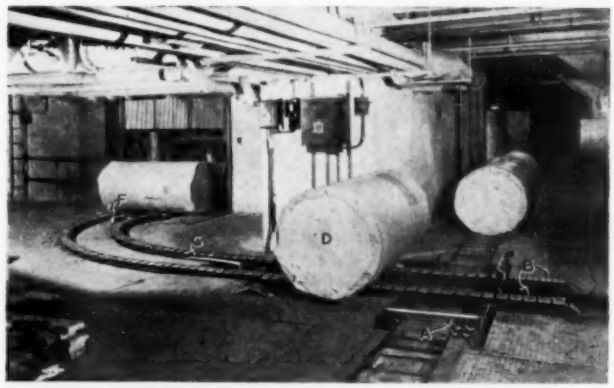


FIG. 8 NOTE TRANSFER CONVEYOR RAISED ABOVE LIVE ROLLERS AND METHOD OF TRANSFERRING TO CONVEYOR FOR GOING AROUND 90 DEGREE CURVE AND FEEDING TO VERTICAL ELEVATOR

take the rolls from the elevator and distribute them to the storage area, and also reclaim the rolls from storage, reload them on the elevator, and carry them to the reel room. A view of the special conveyors in this operation is shown in Figs. 7 and 9. In Fig. 7 are seen the rolls being reclaimed from storage, and they are being transported on an apron conveyor. The cross-lift conveyor is depressed and the live rollers at the transfer point are turning. The live rollers run continuously except when the cross lift is up. A closeup of the method of transferring from aprons to the

cross-lifting conveyor is shown in Fig. 7. When the roll comes in contact with cross-bar *A* the live-roller conveyor is stopped and the lifting mechanism of the two-strand chain conveyors marked *B* is automatically passed onto the two-strand chain conveyor which will carry the roll around a 90-deg. curve and discharge it to the loading fingers of the vertical elevator. The roller marked *E* is also attached to a switch which stops the apron conveyor in case the rolls are too close together or the cross-lift mechanism is raised. It will be noted that these conveyors are all protected with automatic electric stops as indicated by letters

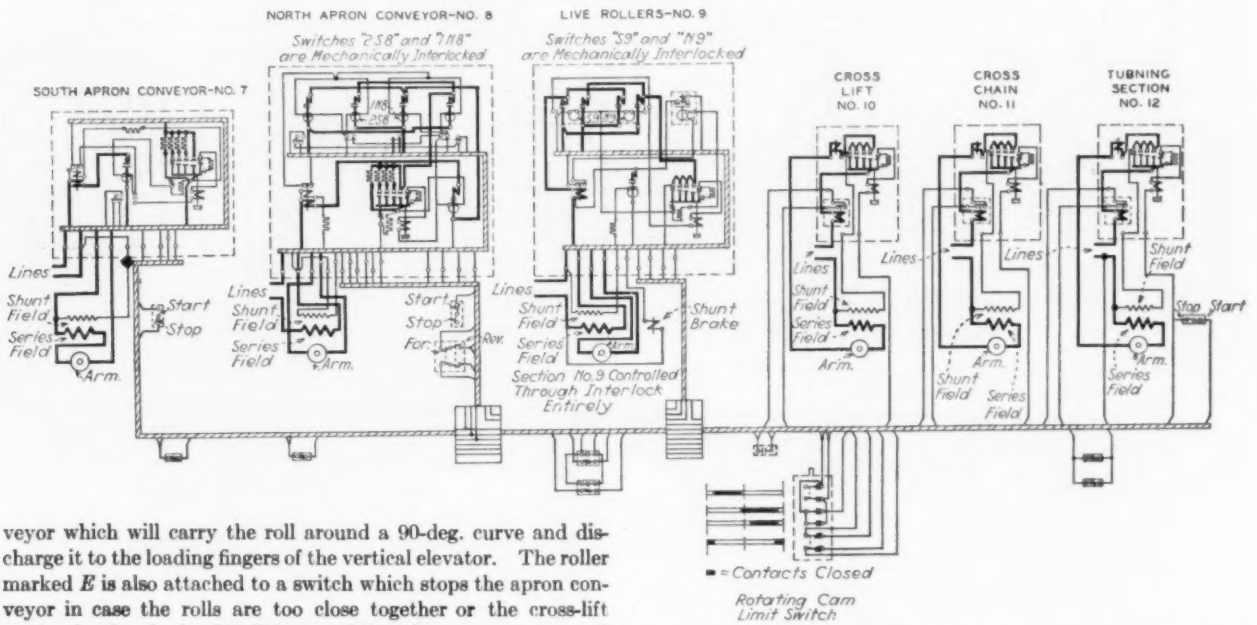


FIG. 9 ELECTRIC WIRING DIAGRAM FOR CONVEYORS ON STORAGE FLOOR AS SHOWN IN FIGS. 7 AND 8

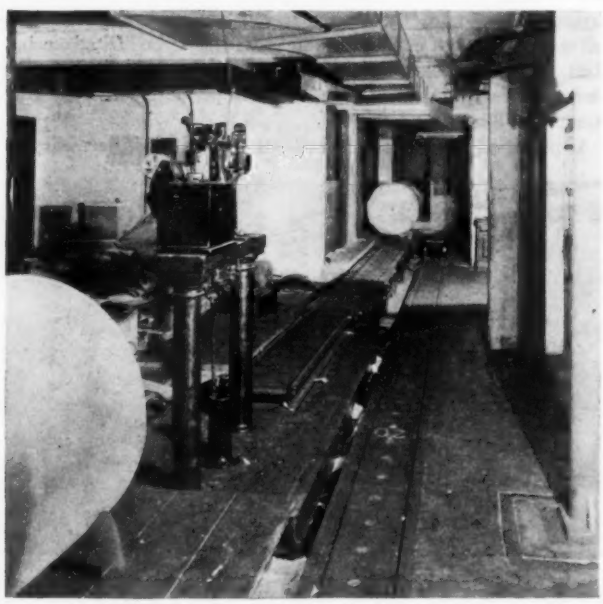


FIG. 10 NOTE ROLL BEING DISCHARGED FROM VERTICAL ELEVATOR TO DOLLEY CAR FOR STRIPPING

C and *F* in Fig. 8 and *A* and *E* in Fig. 7 so that their operation is entirely automatic. Again, without going in detail, in Fig. 9 is shown the wiring diagram for the conveyor shown in Figs. 7 and 8. These conveyors all have to be interlocked so as to prevent congestion, or jamming.

It is unusual to see chain conveyors operating round a 90-deg. curve, but the operation is entirely practical as is demonstrated in this installation. Of course, the conveyors have to be designed to fit the operation and sufficient radius must be allowed so as not to distort the chain. When discharging rolls from the elevator for storage on the basement floor the operation of the conveyors is reversed.

The unloading on the first floor or at the reel room is simple. As the apron conveyor passes in front of the elevator and with a simple discharge, the transfer is made direct to the apron or, if desired, skids can be placed over the apron and discharge can be made to a car as shown in Fig. 10. In this room the paper is weighed and stripped ready for the presses.

It will be seen that to try to handle these rolls with electric trucks or tractors and trailers would necessitate the use of freight elevators, and the labor cost would be higher than is the case with the use of the mechanical conveyors. The speed of 3 rolls per min. is ample and permits quick unloading of barges and cars. The handling of these unwieldy rolls of paper again proves that, with thought given to the problem, the most difficult package or commodity can be handled mechanically.

The newspaper presses are, in a sense, conveyors of the paper from the roll to the folded news sheet, but after the sheet is folded mechanically it is conveyed by special conveyors as shown in Fig. 11, which are specially designed for this operation. After the papers are bundled they are again discharged to belt conveyors which carry the bundles to a chute where they drop one floor to the truck-loading platform.

To the right of the bundle conveyor shown in Fig. 11 is shown a live-roller conveyor for handling stereotype plates. The rollers of this conveyor are driven by a friction belt, and the plates resting on the rollers move forward. The steel plate over the rollers acts as a guard for the plates, and at the same time permits operators to step over the conveyor without danger of slipping on the rolls. In this plant there is a battery of four of these conveyors for handling plates to the four lines of presses, and these four are practically the same as those shown in the bay illustrated in Fig. 11. There are also four belt conveyors for handling bundles of papers after they are tied, and the table over the top of the belt is used for some of the tying-up operations.

It is always interesting to know what horsepower is required

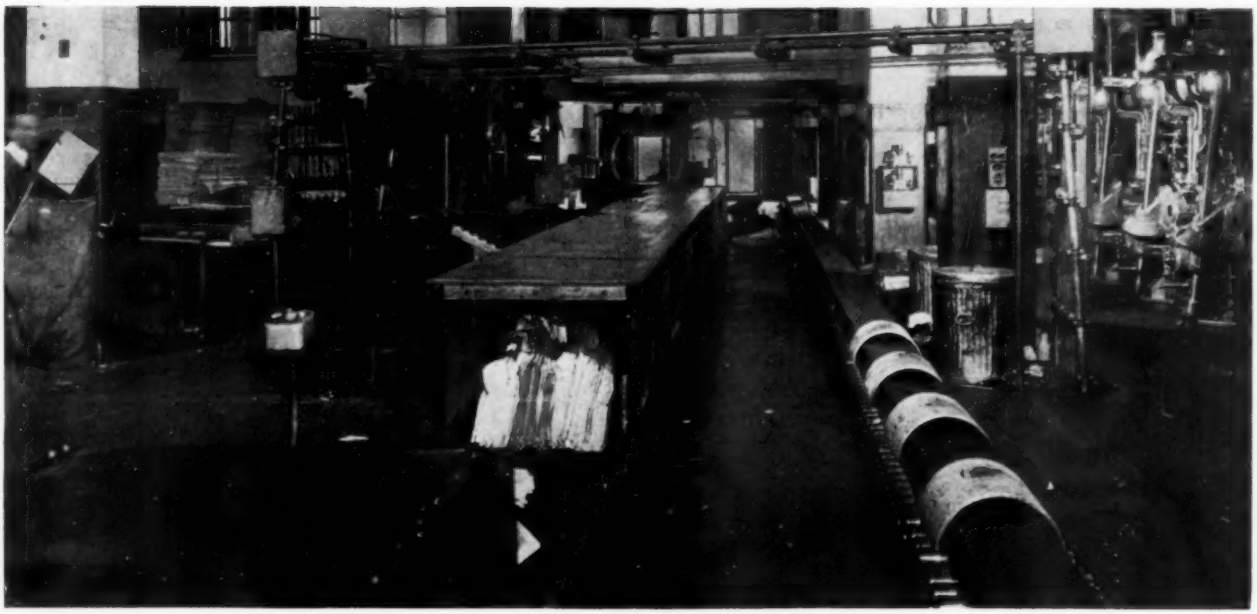


FIG. 11 PARTIAL VIEW OF PRESS ROOM SHOWING PLATE, PAPER, AND BUNDLE CONVEYORS

to operate mechanical-handling equipment. The power of the motors on the various conveyors is as follows: The roll lowering skip requires 15 hp. equipped with a 10-in. solenoid brake, traveling on a cam limit switch. The tunnel-apron conveyor requires a 15-hp. motor. The tunnel live-roller conveyor is equipped with a 3-hp. motor and 8-in. solenoid brake. The cross-conveyor lift for raising rolls off the live roller is equipped with a 5-hp. motor, a rotating cam limit switch, and an 8-in. solenoid brake. This is only for raising the conveyor, while the crossed conveyor itself is equipped with a 3-hp. motor for driving. On the basement or roll-storage floor, each of the two long apron conveyors require a 10-hp. motor. The live-roller conveyor is equipped with a 3-hp. motor and an 8-in. solenoid brake. The cross-lift conveyor is equipped with a 5-hp. motor, a rotating cam limit switch, and an 8-in. solenoid brake, while the drive for this conveyor is 3 hp. The turn-around conveyor is equipped with a 3-hp. motor. The main-roll elevator is equipped with a 40-hp. motor, a 14-in. shunt brake, and an overspeed governor. The motors required for the live-roller conveyor and the belt conveyor are small and, therefore, not listed. While these motors seem to be large, if consideration is given to the operation and the loads to be handled, it will be seen that they are not too large for the capacity required. This installation is a striking example of what can be done on a special handling operation.

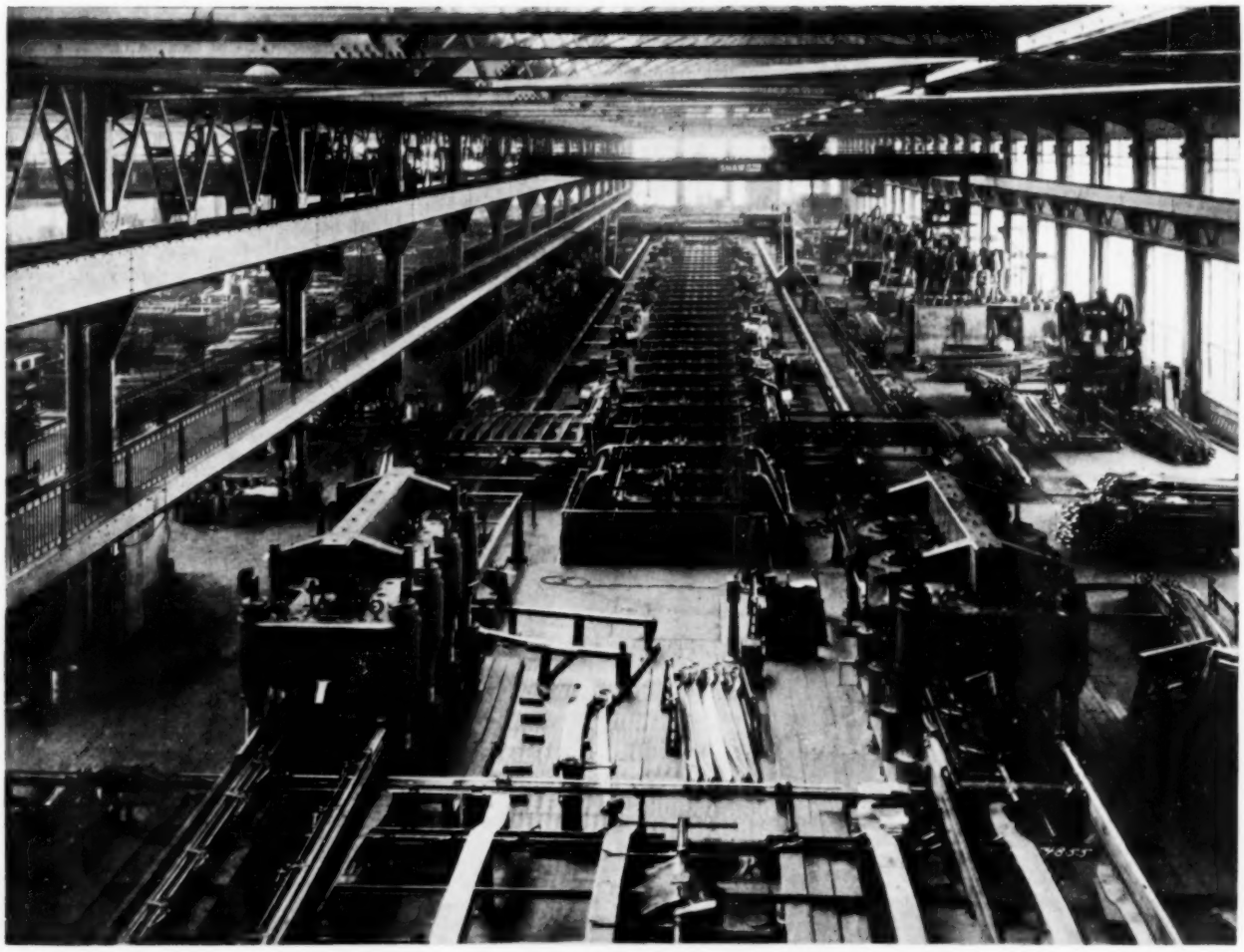


FIG. 1 SIDE-BAR PARTS ASSEMBLY LINE—FORMING PRESSES ARE IN THE FOREGROUND

Handling Materials in an Automatic Frame Plant

BY A. W. REDLIN,[1] MILWAUKEE, WIS.



ABOUT 25 years ago the A. O. Smith Corporation built the first pressed-steel automobile frame in America and has, ever since, remained a leader in this branch of the motor industry. This company also conceived and built the only automatic frame plant in the world, which was completed in 1920, after five years of intensive engineering and research development. The technical staff of the company designed, developed, and supervised the building and erection of the entire plant, and work on refinements and improvements is still being carried on. Today every operation from raw stock to the finished frame, including nearly all handling, is done with automatic machinery, and every part of this huge mechanical monster performs smoothly and with exactness 24 hr. a day for long periods without involuntary shut downs.

The automatic frame plant is divided into two main portions;

[1] Assistant Works Manager, A. O. Smith Corporation. Mem. A.S.M.E. Mr. Redlin served his apprenticeship with the Allis-Chalmers Company, following graduation from high school and a course in Mechanical Engineering. He rose through the ranks of his present position after extensive training in shop practice and factory management. Beginning in 1913 as toolroom foreman with the Brown Motor Company, Milwaukee, he held positions of increasing responsibility with various motor companies, until in 1923 he became connected with the A. O. Smith Corporation.

Presented at the Third National Materials Handling Meeting, Chicago, Ill., March 3, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

the storage building in the rear, and the manufacturing building. In the former is storage space for 50,000 frames as well as 50,000 tons of raw material. Here the raw stock is also received, inspected, and pickled; furthermore, the assembled frames return here to be washed, painted, and dispatched either to storage or shipping platforms. The other main portion, the manufacturing building, houses the bulk of automatic machinery which changes strip steel into complete automobile frames. The actual work is done on the second floor, while the drive and auxiliary equipment extends down to the ground floor.

Steel flows through the plant in a $1^1/_2$-hr. journey, which changes the rusty piles of strip steel into shiny, enameled, precision articles at the rate of one every 8 sec. The strip steel, made to exacting specifications, is picked up from the cars with monorail cranes and is run through an inspection machine at the rate of 900 pieces per hour; being straightened, the length, width, thickness, and curvature of the strips checked, any piece found defective automatically thrown out, and satisfactory blanks delivered in piles to monorail cranes, which move them on to the pickling machine. Here the steel is placed in special crates of 5-ton capacity, which are handled through the different baths by means of a crane operated with remote control. Following pickling, the strip stacks are again picked up by monorail cranes and moved into the manufacturing building at the feed-ends of the two main lines.

Two major types of parts, side rails and cross members, go to make up a frame. Due to their different peculiarities and lengths they each have separate systems of machinery leading to the far end of the building where one large unit takes care of the general assembly of the frame.

The pickled steel passes through the side-bar press line with its four operations entirely handled by conveyors. First the straight strip is "kicked up" edgewise in order to follow the desired contour of the side rail. Next the numerous rivet holes and other openings are pierced, requiring separate presses for the right- and left-hand rails. This is followed by a single blanking press which trims the outline of the blanks, whereupon two more presses take care of the forming operation, folding up the flanges to obtain the conventional channel section. The feeding and unloading of each of these presses is done automatically, and all these many movements are timed and synchronized into a single unit, which does not require manual labor at any point.

Before the side rails can be assembled into a frame, a number of spring hangers, brackets, and other attachments must be riveted on, the ends must be clipped off for accuracy, and certain holes pierced, which must come very close. All this is done in the unit called the "Side-Bar Parts Assembly." Right- and left-hand bars are handled in pairs simultaneously, and are loaded onto trucks automatically. This machine is about 350 ft. long, has 38 trucks and 19 stations, at each of which adjustable machines are performing the various operations required. The finished side bars are automatically removed from the trucks at the end and inspected before being delivered to the adjacent general-assembly unit.



FIG. 2 SIDE-BAR PRESS LINE SHOWING FIRST FOUR PRESSES

Going back to the point where the strip steel enters the manufacturing building, the stacks, meant for cross members, are deposited by the monorail cranes at the loading ends of four cross-bar finishing lines. Each of these is equipped with blanking, piercing, and forming presses, very similar although smaller than corresponding machines for the side-bar press line. Like them, the cross-bar presses are fed automatically and all handling is done with automatic machinery, and following the press line is a conveyor which has a purpose similar to the side-bar parts assembly line. However, much less work has to be done on cross bars, requiring proportionally less space. At the end, the finished cross bars arrive at the general-assembly unit like the side bars.

The general assembly performs two important functions and does both entirely automatically. It collects all the required parts for the frame, assembles them, and puts in all the rivets, finally "setting" each rivet by forming the rivet heads. One conveyor system with trucks takes care of the first function, a so-called "Nailing Machine" assembles the frame and puts in the rivets, while another conveying system equipped with other trucks, handles the last function, the riveting. All three sub-units are synchronized and operated with one single motor.

When the frame is stripped off its truck at the discharging end it is finished and ready to leave the manufacturing building. On a conveyor, running the full length of the building it travels back to the storage building, while on the way it is carefully inspected, and if any part is wrong it is side-tracked on a special repair line and then sent on its way again.

Arriving in the storage building it first has to pass through a washing machine where grease, dirt, etc., is removed in a special automatic machine. Clean and dry it lands at the painting machine. Hanging, one close to the other on an endless chain, the frames slowly pass through this giant machine where special priming paint is sprayed on at the rate of 750 gal. per min. They pass through an oven, baking the paint, then through cooling chambers, emerging after 40 min. as a finished product ready for the customer.

Almost every conceivable type and design of conveyor is used in this automatic plant. Under the pressure of necessity, inventive skill has here brought out a startling variety of material-handling devices. Many old and approved means were utilized, but in addition a great many entirely new devices were invented.

The common reciprocating rail feeder found use in many instances as for the inspection machine and the side-bar and cross-bar press lines. However, it appeared in many new and clever applications. Almost invariably cams were employed for their drive, since intricate timing had to be followed. On most of these feeders it was sufficient to use gravity dogs, one set moving and another stationary. One high-speed conveyor, however, had to be equipped with positive disappearing dogs necessitating one added motion. Adjustable end-guards took

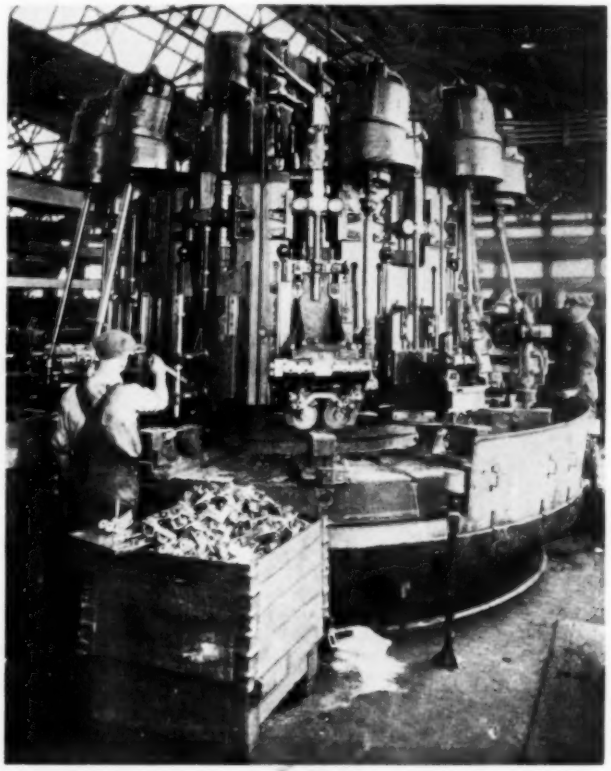


FIG. 3 AUTOMATIC SPRING-HANGER MACHINES—450 CASTINGS PER HOUR MACHINED COMPLETE AT ONE SETTING



FIG. 4 GENERAL ASSEMBLY UNIT WITH RIVET-NAILING MACHINES IN THE BACKGROUND



FIG. 5 OUTSIDE FRAME STORAGE—CAPACITY UPWARD OF 200,000 FRAMES

care of guiding the blanks and, as on nearly every type of feeder, safety devices were provided, which automatically stop the whole unit in case anything goes wrong.

A very interesting solution of a feeder problem is a double reciprocating overhead carriage operated with wire ropes for the feeding and unloading of the off-setting press. This device picks up the steel strip with magnets and does a perfect job at very high rates of speed.

Another clever device feeds and unloads the forming presses. It has disappearing fingers which simultaneously pick up a blank from the cross conveyor underneath and a finished side bar in the press; then rushes 20 ft., stops, and deposits the bar in a crate and the blank in its exact position on the forming die. Split seconds and perfect timing are absolutely essential here and it is well safeguarded by sensitive electrical devices.

Feeders and such devices are, however, to be found in many plants and in connection with many machines, but entirely new problems faced the designers of the side-bar parts assembly line. Thirty-eight trucks, each one a real machine in itself, with four smaller carriages, had to be put through their paces according to a very difficult timing diagram. Swift movements, sudden and accurate stopping and starting of such great masses involved staggering loads and an inertia which could not be overlooked. Enormous cams, of a size and design nowhere else to be seen operate this machine, and powerful balancing devices are provided to absorb the suddenly released energy. Running on rails, the trucks advance intermittently on an upper level. At each station the trucks are doweled, the smaller carriages are simultaneously released, thrust out two to each side and also doweled, thus carrying the side rails, to be worked on, into the waiting machines. These quickly perform their work; the carriages retreat and the trucks advance to the next station where the same cycle is again repeated; each consuming a total of but 8 sec. At the end of the line, truck after truck is unloaded and lowered onto the return tracks on the lower level, where a screw-like device propels them back to the starting end at uniform speed. Raised to the upper level by means of an elevator they receive new loads and repeat the performance.

In magnitude and completeness it has nothing on the next unit, however, which is the general assembly. Here two track systems with trucks are combined into one unit, weights are still greater, and the assembling and nailing machine adds to make this one of the most complicated and, to the visitor, most baffling machines to be found any place. The powerful drive, with its string of enormous cams, resembles that of the preceding unit, the side-bar parts assembly line. In one respect, however, does this unit present a new angle of conveying. Unlike the previous unit, the work is not brought up to the machine, but the frames, now assembled, stay on the trucks while the machines are brought to the work. This is accomplished by having the

riveting machines mounted on platforms, provided on each side of each truck line. A stationary steel floor over the platforms makes it possible for the men to walk around among the individual machines. The procedure is then for the trucks to run intermittently, stopping for a given length of time at each station. Here the truck with the frame on it is lifted up on dowels, the riveting machines advance from each side, carried on the platforms, and perform their work of setting the rivet heads. Very ingenious heads were invented which enable any rivet to be set no matter how it is located, with a few standard types of machines. After the work is done the jaws of the machines open up, the machines retreat, and the trucks then advance another step and the whole performance is repeated.

The average frame is composed of some 125 parts and 500 to 600 operations are required to produce the finished frame. The automatic plant alone turns out 10,000 such frames every 24 hr., the machinery performing approximately four million operations in a day's production. It is indeed a sizeable figure, and it means something when one considers that every one of the operations must be performed correctly, or such a plant would not be practical. Still more significant is the feat of manufacturing the more than 100 parts for a frame in as many different places in the plant, to have them meet at one place on schedule, to piece them together at the rate of a complete unit every 8 sec., and to repeat this accurately 10,000 times in succession every day. Visualize what it means to produce springy, flexible-steel stampings so accurate and so uniform that any one piece will match any accompanying frame part so perfectly that no interference ever occurs, and so that all holes line up exactly. This is not only desirable but absolutely necessary since only a fraction of a second is available to put in all the rivets.

It may be of interest to mention that more than 100 tons of steel flow through the automatic plant every hour and a half. Transportation facilities, accordingly, must have an unusual capacity. The tremendous production of 10,000 frames per day also calls for rapid disposal. Storage space is available in the building and outside the building, which will accommodate 150,000 frames. Extensive loading platforms are also provided from which as many as 12,000 frames have been loaded into cars in 9 hr.

It takes 50 min. actually to manufacture a frame in the automatic plant. An added 40 min. is consumed in cleaning and painting the frame before it is ready to be shipped. This makes a total of $1^1/_2$ hr. for the entire fabrication process.

The manufacturing building has a productive capacity of 450 assembled frames per hour, and in order to supply parts, each unit preceding the general assembly has a capacity of 450 pieces per hour. For similar reasons it is necessary to have the same capacity for the raw-material handling machines. Thus the inspection machines can handle 900 strips per hour, the pickling machines upward to 1100 tons of steel per day, and finally the painting machine can turn out 450 frames per hour.

Fully automatic production is already common practice in bulk manufacturing. What this company has accomplished shows that the principle can be applied successfully and on a large scale to assembly operations. If experience is any guide, a more complete use of machinery for all routine operations and the handling of materials is not only possible but also very profitable.

MSP-52-1

Progress in Machine-Shop Practice

Contributed by the Machine Shop Practice Division

Executive Committee: W. J. Peets, *Chairman*, Carlos de Zafra, *Secretary*, K. H. Condit, W. W. Tangeman, and J. W. Roe

MEASURED by the advances in machine-tool design, the progress in machine-shop practice during 1929 has been considerable. Since the greatest part of any possible advance in this art centers about the availability of improved production equipment, this particular measure is probably as significant as any that could be selected.

The second machine-tool exposition held by the National Machine Tool Builders' Association served to introduce a record number of new pieces of machine-shop equipment. This show took place in Cleveland early in the autumn, and was attended by some 25,000 visitors, almost all of whom were the chief executives, operating heads or specifying officials of machine-tool using organizations. Many men of long experience in the industry expressed the conviction that never before had so many prominent men of the industry gathered in one place. And they were well repaid for coming, because they saw in operation something like 150 new machine tools, as well as many others that had been on the market for some little time, but were still sufficiently recent in design to be far in advance of much of the equipment that is now in use.

The following statement, taken from the Show Number of *American Machinist*, outlines the more important developments:

"The substitution of automatic for hand operation on a number of the machines developed is a prominent feature in the equipment placed on exhibition. Wherever feasible this improvement has been made. Such developments have demanded no little skill and ingenuity on the part of the machine designer and builder. Radical changes were required in most cases. The resulting equipment requires more care in set-up, more certain means of lubrication, and may involve a higher maintenance charge on account of the refinement of parts introduced. On the other hand, sturdiness has been added in most cases in developing or redesigning such types of equipment. Adjustments in its use, of course, must be made by skilled mechanics who are experienced in special machines, rather than by the ordinary machine operator. But to offset any increased initial cost, and any added operating or maintenance expense, a vast increase in output has been brought about, making the unit cost of products manufactured only a fraction of what it was when former types of equipment were employed.

"Mechanical features of operation are well typified by a feeding device developed and applied to one of the well-known lines of automatics. No operator is now required for this machine. A long runway holds a store of the work, and the two-arm work-feeding mechanism picks up one part at a time and brings it into position between two tool-holding slides, one of which carries turning tools, and the other grooving, facing, and forming tools, where it is held between centers. The work is driven by the mechanism. When the machining has been completed a second arm automatically moves up and discharges the piece on a runway carrying it away from the machine, while the first arm moves in a new part for machining. The machine continues to operate in this way until stopped by the push-button control.

"The present tendency in machine design is rather away from the single-purpose machine. For high production and very special work the single-purpose tool, of course, will always find a market. But its limitations when sudden and radical changes in the design of products come about are causing machine-tool builders to devote much less attention to this type of equipment, and more attention to the provision of special fixtures adapting standard tools to definite production jobs, and to the design of unit-type equipment to be built up into various combinations suited to the requirements of different jobs. This tendency is most decided and undoubtedly will continue to be a major factor in machine design for a long time to come.

"Even in cases where machines have been developed for special purposes there have been introduced certain features which widen the uses of the equipment. For instance, a certain type of grinder designed for special railroad equipment work on a production basis has been adapted so that the machine can be used for tool grinding or production grinding on other types of work.

"There is a definite tendency toward a more extensive use of hydraulic mechanisms on numerous types of machine tools. At the show, new applications of hydraulic feed to equipment such as lathes, grinders, smaller sizes of milling machines, multiple-spindle drills, honing machines, and broaching machines were demonstrated. Further improvements in indexing have been made on machine tools placed on exhibition this year. One outstanding development is the application of the double Geneva motion on a work-rotating chucking machine with an unusually large turret that is indexed in four positions 90 deg. apart. This machine also represents several other outstanding developments in machine design.

"Increasing attention to lubrication is decidedly evidenced by the equipment developed during the past year. No definite tendency toward any one type of lubrication is to be discovered. Some manufacturers have adopted central, forced-feed systems for their equipment. Others prefer gravity feed from central reservoirs. Still others retain the oil cups for individual bearings. Combinations of systems are also of frequent occurrence. For instance, the chucking machine mentioned employs a central lubricating system for the main bearings of the machine, but a gravity-feed reservoir for the heavy turret, to avoid the use of slip joints which would be required if the main system were utilized for turret lubrication. One manufacturer is introducing a forced-feed lubricating system operated periodically under the control of an electric timing clock. Oil filters are also finding more extensive application. In no case is lubrication neglected as a factor in machine operation and maintenance.

"Many other factors have become of increasing importance in machine design during the past year, and characterize practically all of the equipment placed on exhibition at the show. Among those factors which have received special consideration are: A higher degree of accuracy in the parts comprising machine tools and equipment, provisions for a higher degree of accuracy in the products turned out, ease and convenience of operation, reliability of service, compactness of design, decrease of floor space occupied, simplicity of drive, reduction of power consumption through the liberal use of ball and roller bearings, higher grades of steel and alloys for journals, spindles, gears, and other operating parts of machines, convenience of inspection and cleaning, provisions for the removal of chips, facilities for mechanical handling, and the features of higher production, greater automaticity, and adequate lubrication, which have been discussed."

Further evidence of the ability of machine-tool builders to cooperate was given by the adoption of a standard color for machine tools. With very few exceptions all machines exhibited at Cleveland were finished in this color, and the pleasing appearance of uniformity was sufficient justification for the move. Most of the builders who have adopted the standard color are making a small extra charge for finishing their products in a special color specified by the customer.

Because of the high rate at which machine-tool plants have been operating for the past year, the designing and building of the new models exhibited was attended by considerable difficulty. In fact, some of the innovations intended for Cleveland were not finished in time and will be announced later. This situation augurs well for the future. Not only are there more new machines on the way, but because of the record-breaking activity of the builders, profits have been more nearly commensurate with the efforts of the engineers and construction forces, and consequently there will be more money in the future for the research work that must be done if the art is to continue to advance.

The facilities of the machine-tool building plants have also been increased during the year. Several new engineering buildings have been erected, and plant additions have been made to take care of greatly increased orders. Overtime and double shifts have been common throughout the industry.

Undoubtedly the most important single development of the year has been the progress made in adapting the new tungsten carbide cutting tools to machine-tool uses. It must be admitted that many disappointments have accompanied the efforts to apply tungsten carbide, but these were to be expected, and on the whole there has been appreciable progress.

Unqualified success has attended the application of this material to the machining of rubber, fiber, and similar materials; and to the machining of brass, bronze, aluminum, and the like; also in most cases where cast iron has been the material to be cut. But like success cannot be reported in cutting alloy steels. Here the fragility of tungsten carbide incident to its extreme hardness has led to failure where there was the least chance of chatter. Much of the difficulty is now attributed to the means of holding the cutting bit to the shank of the tool. Brazing, atomic-hydrogen welding, and more recently mechanical means such as dovetailing have been used for this purpose, but with results that indicate the necessity of further research.

It must be admitted that there has been considerable disappointment at the failure of this new cutting material to solve all the difficult machining problems of the shop, but it should be observed that much of this disappointment is entirely unjustified, and should not lead potential users to distrust its future possibilities. Too much was expected of a substance about which there was insufficient knowledge. When that knowledge has been obtained there is every reason to believe that tungsten carbide will do all that has been claimed for it.

A year ago there was a general belief that tungsten carbide would bring about an immediate revolution in machine-tool design. This belief has not been realized. A few machines have been speeded up to meet the requirements of the new material, but at least some of the more recent designs have been found quite adequate to develop the full possibilities of it. Evidently the change in design is to be an evolution rather than a revolution.

An interesting effect of the introduction of tungsten carbide has been the improvement in high-speed steels. The threat of competition has driven the producers to extra efforts, and the result has been that some of the current products show cutting ability as much as 25 per cent ahead of anything that has been available hitherto. Further advances are probable, especially because experience with tungsten carbide will accustom the user to the brittleness of a diamond-hard alloy, and will thus lead him to accept some lessening of the toughness of high-speed steel if it can be made harder. When the user accepts this situation the maker of high-speed steel can develop steels with entirely new characteristics.

While the new cutting materials have occupied the center of the stage, developments of other new materials used in the machine shop have proceeded apace. Among the important ones is high-test cast iron, practically a new material. Cast iron of as high as 85,000 lb. per sq. in. tensile strength has been produced, and one foundry is consistently attaining strengths of 65,000 lb. Four processes are in use, all depending on the holding of the liquid iron at a high temperature, in the neighborhood of 3000 deg. fahr., until the carbon has been dissolved, thus preventing the formation of the plates that weaken the structure of ordinary iron.

The research organizations of the aluminum, brass, and nickel companies have perfected many new alloys and improved older ones. Plastics have come very much into favor, and are replacing metals in some instances. "Stainless" steels have attracted considerable attention, and nitrided steels have found new uses.

All of these advances point to the need for more and better organized research work in the machine-shop-practice field. A little is being done by a few of the larger units, but in the aggregate not much has been accomplished. From the very nature of machine-shop work, and the absence of any shops of dominating size, the problem of how to organize research of the kind needed is difficult. Probably the only solution is a central institute or laboratory to be supported by contributions from the various trade associations and individuals in the industry, but before such an institution can be established there must be an awakening to the true significance of fundamental and applied research. Much educational work lies ahead of any group undertaking to solve this particular problem, but the necessity is so great that it will justify large effort.

Standardization work in the machine-shop-practice field is in somewhat better shape than is research. Only one standard has been approved by the American Standards Association during 1929, that for tool-holder shanks and tool-post openings, but the following are in type and are practically completed by the sectional committees: Spur-gear tooth form, full depth system; inspection of gears; gear materials and blanks; taps, cut and ground threads; milling cutters; radial ball bearings; slotted-head screws; line work on drawings; and motor-frame dimensions.

During 1929 some progress has been made in improving management methods, and particularly cost methods. The outstanding example is the work of the National Machine Tool Builders' Association under the direction of its general manager and his staff cost consultant. Much progress has been made in getting uniformity of cost methods so that true comparisons are really possible. By this means the plant management can tell with some assurance whether it is efficient as compared with its competitors. Other branches of the field would do well to take steps toward the same goal.

Management throughout the industry has evidently accepted the soundness of the modernization principle. The greater part of the record business of 1929 has come from replacements of obsolete equipment rather than from plant enlargements. A certain amount of replacement business has had to be postponed by equipment builders because of their inability to make deliveries. The recession in the automobile industry, and the general slowing down that seems likely until the confidence shaken by the recent stock-market gyrations has been restored, will give an opportunity for the builders to catch up on their orders, and put their full effort into campaigns to replace the vast quantity of obsolete equipment still in use.

K. H. CONDIT

MSP-52-2

Power Required to Drill Cast Iron and Steel

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This paper presents the results of drilling tests on cast iron and steel. Drills ranging in diameter from 1/2 to 1-1/2 in. of the standard twist-drill type were used. The drills were considered sharp in all tests. A coolant consisting of one part of soluble oil and 16 parts of water was used in all tests. The materials cut consisted of one regular machining cast iron and one cast iron made up of 20 per cent charcoal pig iron, together with 17 steels of a wide variety of chemical analyses, which were selected to cover the steels commonly used in modern manufacture.

Data as to drilling torque, thrust, computed horsepower at the drill point, and net horsepower supplied to the machine as measured on a recording wattmeter are given under two headings: commercial tests and special tests. All commercial tests were run at a peripheral speed of the drill of approximately 60 ft. per min. The feed for each drill size was as near to those given in the usual commercial-drilling table as the change gears available would permit. They were as follows: 0.009 in. per rev. feed for the 1/2-in. diameter drill, 0.011 in. for the 5/8-in. drill, 0.012 in. for the 3/4-in. drill, 0.013 in. for the 1-in. drill and 0.015 in. for the 1-1/4- and 1-1/2-in. diameter drills.

Special tests were run on various cast irons and steels so that the influence of the speed, feed, and drill diameter could be determined, in order that the results of the commercial-drilling tests could be extended to cover any other conditions of drilling for each material. It was found from these special tests that the thrust for both cast iron and steel increased in direct proportion to the drill diameter d; that the torque increased in proportion to d^2 for cast iron and $d^{1.8}$ for steel. The thrust increased with an increase in feed f, but at a rate as slow as $f^{0.6}$ for both cast iron and steel. The torque increased as $f^{0.6}$ for cast iron, but $f^{0.78}$ for steel. It was found that the torque and thrust remained practically constant over the whole range of speeds covered from 74 to 441 r.p.m. for each drill size and feed.

An attempt is made to correlate the hardness values of the materials determined by the Brinell, Rockwell, scleroscope, and Herbert pendulum hardness testers, with the results obtained from the drilling tests.

It is concluded that no satisfactory relation exists between these properties.

THIS paper presents results of a series of tests in drilling steel and cast iron with sharp standard twist drills ranging in diameter from $^1/_2$ in. to $1^1/_2$ in. Data were obtained of the torque, thrust, and net horsepower developed at the point of the drill for some of the modern high-speed-steel twist drills, when cutting a variety of types of steels and cast irons used widely in modern industry.

TABLE 1 MATERIALS USED IN DETERMINATION OF POWER IN DRILLING, SHOWING THE S.A.E. SPECIFICATIONS, THE CHEMICAL ANALYSIS, THE HEAT TREATMENT, AND THE BRINELL, ROCKWELL, AND SCLEROSCOPE NUMBERS

Bar no.	S.A.E. specifications	Chemical analysis	Heat treatment deg.	Hardness: Brinell Dia.	Brinell No.	Rockwell "B" scale	Scleroscope no.
1	1020	Commercial	None	5.1	137	84	29
2	1045	Commercial	Normalize 1600 Anneal 1475	4.75	159	82	28
3	2320	Commercial	Anneal 1600	4.7	163	85.5	25
4	3120	Commercial	Anneal 1600	5.0	143	75	24
5	3135	Commercial	Normalize 1575 Anneal 1500	4.35	192	88.5	29
6	6150	C. 0.50 Mang. 0.20 Chr. 0.80 Van. 0.20	Normalize 1650 Anneal 1550	4.4	187	86.5	29
7	3250	C. 0.50 Chr. 1.00 Ni. 1.75	Normalize 1650 Anneal 1475	4.2	207	92.5	30
8	3140	C. 0.50 Chr. 0.60 Ni. 1.25	Normalize 1650 Anneal 1500	4.3	196	92	30
9	2330	Commercial	Anneal 1500 Reanneal 1400	4.25	202	93.3	32
10	2340	Commercial	Anneal 1500 Reanneal 1400	4.2	207	93.5	32
11	6120	Commercial	Anneal 1500 Reanneal 1400	5.1	137	76.5	25
12	6130	Commercial	Anneal 1500 Reanneal 1400	4.8	156	81.5	28
13	6140	Commercial	Anneal 1500 Reanneal 1400	4.7	163	85.5	28
14	9250	Commercial	Anneal 1500 Reanneal 1400	4.25	202	93	32
15	Chr. Molyb.	C. 0.33 Si. 0.20 Mang. 0.50 Ph. 0.011 Su. 0.010 Chr. 0.66 Molyb. 0.18	Anneal 1500 Reanneal 1400	4.8	156	77.5	27
16	Chr. Molyb.	C. 0.28 Si. 0.23 Mang. 0.52 Ph. 0.028 Su. 0.017 Chr. 0.65 Molyb. 0.19	Anneal 1500 Reanneal 1400	4.8	156	79	27
19	1095	Tool steel	Anneal		154	85	25
18	C. I.	Charcoal	As cast	4.7	163	83	32
20	C. I.	Regular	As cast		143	76	30

Materials Drilled

The materials drilled in these experiments consisted of 17 steels and 2 cast irons. The steels were obtained in bars 2 in. wide by 4 in. deep and from 14 to 20 in. long. They were selected to represent a number of the more commonly used steels in industry. All materials are listed in Table 1. The steel bars are numbered from 1 to 16 inclusive, and 19, while bars 18 and 20 are cast-iron test pieces, also 2 in. wide by 4 in. deep and 4 ft. long, as cast in the University foundry. The bar number for each steel is given, with the S.A.E. specification, which, in some instances, is augmented by the chemical analysis.

The steels were given a heat-treatment at the mill, to provide a grain structure and degree of hardness which was thought suitable for machining purposes. These heat-treatments are indicated in Table 1. Cast-iron bar 20 was a regular high-silicon iron of the type commonly used for machining purposes. It consisted of C, 3.52; Si, 2.18; S, 0.108; Mn, 0.69; P, 0.489. Cast-iron bar 18, was made up of about 25 per cent by weight of charcoal pig iron.

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Contributed by the Special Research Committee on Cutting of Metals and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

The surface, 1/4 in. in depth, was milled off the edge of each bar at the end so as to present a surface about 2 in. square. These surfaces were then filed smooth, after which hardness tests were made on them. The Brinell, Rockwell "B" scale, and scleroscope hardness numbers are also given in Table 1 for each bar.

Drills Used

The drills used in these experiments were furnished by the National Twist Drill and Tool Company, and were selected as being representative of those drills corresponding with their standard specifications for taper-shank, high-speed-steel twist drills. They were furnished in sizes of 1/2 in., 5/8 in., 3/4 in., 1 in., 1 1/4 in., and 1 1/2 in. diameter. Each size was furnished in duplicate, one stamped R and the other stamped L, for purposes of identification. The drills were ground in an S.P.K.

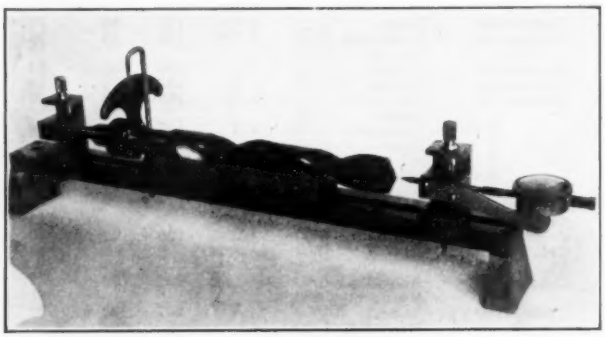


Fig. 1 Drill Measuring Instrument for Determining Cutting-Edge Clearance, and Advance

Blau drill grinder with a drill overhang from the jaws, varying for each drill diameter, as set by a gage, as follows:

Drill diameter inches	Drill overhang, inches
1/2	0.275
5/8	0.300
3/4	0.325
1	0.375
1 1/4	0.425
1 1/2	0.475

The head of the machine was also carefully set to the proper drill diameter, so that with the overhang specified, that drill could be reground without changing the various drill-point angles.

The grinder forms the drill point so that it has a conical surface back of the cutting edge. In each case after grinding, the drill was measured on the special measuring instrument shown in Fig. 1, which employed a dial gage with its spindle placed parallel to the axis of the drill, but off center to make sure that the cutting edges at the periphery were advanced to the same relative position or lead to cut chips of equal thickness.

TABLE 2 LIST OF THE DRILLS USED IN THE TESTS, WITH MEASUREMENTS

Drill size in. and no.	Outside diam. at point in in.	Web thickness at point in in. after first and last grind	Point included angle Deg.	Point included angle Min.	Chisel Edge angle Deg.	Chisel Edge angle Min.	Helix angle at end Point Deg.	Helix angle at end Point Min.	Helix angle at end Shank Deg.	Helix angle at end Shank Min.
1/2 R	0.499	0.0792–0.083	121		129		29		27	45
1/2 L	0.4988	0.0805	120	30	130		29	20	24	30
5/8 R	0.6242	0.0943–0.0945	121		129		32		31	
5/8 L	0.6244	0.0894–0.091	121		131		31	55	29	
3/4 R	0.7494	0.1071–0.1072	121		134		31	10	28	30
3/4 L	0.7493	0.1110–0.1115	121		134		30	55	28	10
1 R	0.9989	0.1346–0.1395	121		136	30	31	15	28	10
1 L	0.9990	0.1340–0.1495	120	30	136		30	55	27	55
1 1/4 R	1.250	0.1580–0.173	120	30	138	30	30	10	28	05
1 1/4 L	1.2490	0.1595–0.1675	120	30	139		31		27	
1 1/2 R	1.500	0.1845–0.2135	121		138		31	20	29	
1 1/2 L	1.500	0.1873–0.214	121		135		31	30	29	15

Newly sharpened drills were again reground if one lip was in advance of the other by more than 0.001 in. This precaution was taken to eliminate any influence on the test results of any chip thickness other than that desired. If, for instance, a drill one inch in diameter had a variation in lead of one cutting edge over the other of 0.005 in., which is not uncommon in drill grinding, and the drill was being fed into material at the rate of 0.013 in. per revolution, the advanced cutting edge would remove 0.0115 in. feed per revolution, while the lagging cutting edge would remove only 0.0015 in. Inasmuch as thick chips are removed more efficiently, that is, with less power per cubic inch of metal removed per minute, than thin chips, the resultant torque and thrust, in the case of uneven chip thickness, might not equal those for a correctly ground drill.

TABLE 3 DRILL CLEARANCE ANGLES REQUIRED BY FEED AND AS ACTUALLY GROUND

Size of drill, in.	Letter	Outside diameter in.	Width of chisel point, in.	Practical feed in. per rev.	Feed helix At periphery Min.	Feed helix At chisel edge Deg.	Feed helix At chisel edge Min.	Clearance at periphery, as ground Deg.	Clearance at periphery, as ground Min.
1/2	R	0.499	0.115	0.009	20	1	25	5	20
5/8	R	0.625	0.15	0.011	19	1	21	5	0
3/4	R	0.7495	0.16	0.012	17	1	19	4	40
1	R	0.999	0.205	0.013	14	1	10	5	0
1 1/4	R	1.250	0.235	0.015	13	1	9	5	0
1 1/2	R	1.500	0.25	0.015	10	1	5	5	0

Table 2 lists the drills used in the tests, and gives the values of various measurements, such as the outside diameter, the web thickness at the point after the first grind and again after being ground at the conclusion of the tests, the point angle included between the two cutting edges, the chisel-edge angle or the angle the chisel edge makes with a cutting edge, and the helix angle of land measured at the point and at the shank.

The clearance angle actually ground back of the cutting edge at the periphery is shown for each drill in Table 3. These angles are approximately five degrees for all drill sizes. The clearance angles were determined graphically, with the use of a universal drafting machine, after rolling the twist drill over the back of a sheet of carbon paper placed on plain paper, and taking measurements from the print on the plain paper.

This actual clearance angle was also determined more accurately by the special clearance measuring instrument for one point back of the cutting edge, adjacent to the chisel edge, and a second point back of the cutting edge, adjacent to the periphery of the drill. The dial-indicator reading was set at zero for each position, when the point of the indicator rested directly on the cutting edge. The drill was then rotated 3 deg., and the new dial-gage reading observed. The dial-gage readings adjacent to the periphery and chisel edge were carefully determined for the 5/8-in. and 1-inch drills for each increment of 3 deg. for a total rotation of the drill of 60 deg. The gage readings were plotted against the angle of rotation in degrees, and lines were obtained which were practically straight. This proved that the clearance angle was constant at all points back of the cutting edge, for each position. Also, the two lines for each drill passed through the origin and practically coincided, showing that the longitudinal relief for a given rotation was the same at the periphery as adjacent to the chisel edge. These readings were then reduced to the clearance angle back of the cutting edge for the two positions, and values were obtained as shown in Table 4. It is seen that the clearance at the end of the chisel edge is more than twice that near the periphery for each drill size. The values of the clearance at the periphery as ground, shown in Table 3, differ slightly from those determined by the measuring instrument given in Table 4, for a point near the

TABLE 4 THE CLEARANCE ANGLE, BACK OF THE CUTTING EDGE, AS DETERMINED BY THE SPECIAL CLEARANCE MEASURING INSTRUMENT

Drill diameter, in.	Clearance angle — Near periphery Deg.	Min.	Adjacent to chisel edge Deg.	Min.
5/8	4	51	12	22
1	6	1	13	45

TABLE 5 SPEEDS AND FEEDS USED IN COMMERCIAL DRILLING TESTS

Diameter of drill, in.	Drill speed for 60 ft. per min., r.p.m.	Drill speed as set up r.p.m.	ft. per min.	Feed, in. per rev.
1/2	458	441	57.5	0.009
5/8	367	360	59	0.011
3/4	306	296	58	0.012
1	229	228	59.7	0.013
1 1/4	183	178	58	0.015
1 1/2	153	153	60	0.015

outside periphery, first, because the angles were not measured at the same distance from the drill center, and second, because the values at the periphery in Table 3 were obtained graphically, using carbon paper, while those in Table 4 were determined analytically from the gage measurements near the periphery. The latter are believed to be more accurate. These clearance angles, while smaller than those usually specified, seemed adequate for the feeds used in this series of experiments, as in no instance was rubbing observed on the end of the drill back of the cutting edge.

The angles, or relief, back of the cutting edge on the end of the drill, as required by the advance of the drill or the feed per revolution (feed helix), at both the periphery and adjacent to the chisel edge, are given for each drill size in Table 3, for the feed in inches per revolution for each drill size, as actually used in the commercial tests. (See Table 5.) For the 5/8-in. diameter drill, operating with a feed of 0.011 in. per revolution, the feed helix at the periphery is zero deg. and 19 min.; at the end of the chisel edge it is 1 deg. and 21 min. The actual clearance between the end of the drill and the material, is the clearance angle as ground, reduced by the feed-helix angle required by the advance of the drill. The feed-helix angle at the periphery of the 5/8-in. R drill is zero deg. and 19 min., as shown in Table 3. The total clearance as ground is 4 deg. and 51 min., as shown in Table 4, so that the drilling clearance is the difference, or 4 deg. and 32 min. Similarly, the actual clearance at the end of the chisel edge for the 5/8-in. drill is 12 deg. and 22 min. (Table 4), less the feed-helix angle of 1 deg. and 21 min. (Table 3), or 11 deg. and 1 min.

Influence of Clearance Angle Variations on Torque and Thrust

In a series of experiments with a group of drills having point angles of 118 deg., but various helix angles, B. W. Benedict[3] showed that with each drill ground successively to have clearance angles at the periphery of 2, 4 1/2, 7, 10, 12 1/2, and 15 deg., the torque is practically constant. The drill diameter was one inch and the drill with each clearance was tested in cast iron at four different feeds, 0.0056, 0.0133, 0.0256, and 0.041 in. per revolution.

Considering the thrust, uniform and pronounced tendencies were observed. The thrust was highest for the lowest clearances and gradually decreased as the clearances increased to about 10 deg. when the curve which was concave upward, became practically horizontal.

Testing Equipment

The testing equipment was devised so that the torque and thrust as developed at the drill point could be determined, as well as the input or power developed by the motor. The testing equipment consisting of a drill press, a drill dynamometer with gages, and the recording wattmeter, are shown in Fig. 2. The drill press was a No. 2 manufacturing type Colburn press, which was driven by a 5-hp., 220-volt, 3-phase, 60-cycle motor attached to the rear of the column. The motor drove the tight and loose pulley, through a short belt. A gear pump was provided for raising the coolant, of one part of soluble oil to sixteen parts of water, from the tank in the base of the column to the drill.

The drill dynamometer was of such a design that the torque and thrust could be measured independently. The pressure

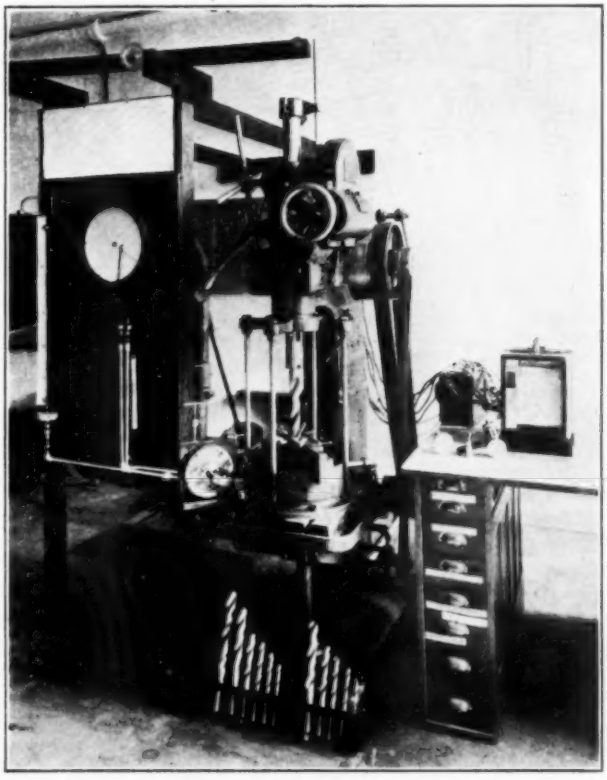


Fig. 2 Drill Press and Equipment Used in Tests

developed by the drill was exerted directly on a plate resting on a rubber diaphragm, just above the dynamometer base. Water underneath this rubber diaphragm was compressed, due to the thrust of the drill, and the pressure was transmitted to one pen of the gage through the 1/8-in. pipe. The plate resting on the rubber diaphragm which carried the thrust load was made to form the lower race of a large ball bearing consisting of sixty-four 1/2-in. balls, so that the table of the dynamometer was free to rotate except for the arm extending to the left, which had a bearing against a piston resting on a second and smaller rubber diaphragm. This arm was one foot long measured from the center of the dynamometer, which corresponded with the center line of the drill spindle. The pressure on this small rubber diaphragm or torque diaphragm compressed water back of the rubber. This pressure was transmitted through a 1/8-in. pipe, leading both to the mercury-column base, and the second pen of the gage. The mercury column had a scale which had units larger (more sensitive) than those of the gage, but which did not have the range permitted by the gage. To prevent tilting of the dynamometer table on the thrust rubber dia-

[3] Selected Bibliography Reference No. 7, p. 38, par. 12, and Figs. 24 and 25.

phragm, a spider fitted around the spindle housing was attached to the table of the dynamometer by four vertical rods. To eliminate friction and to permit the spider to rotate freely with the table as the torque was applied or to be forced downward with the dynamometer table as a thrust was applied, the bearing between the spider and the spindle housing consisted of twenty-four $^1/_2$-in. balls mounted in appropriate races.

The chart of the recording gage was made to rotate, to register the travel of the spindle, by means of a fine wire which passed

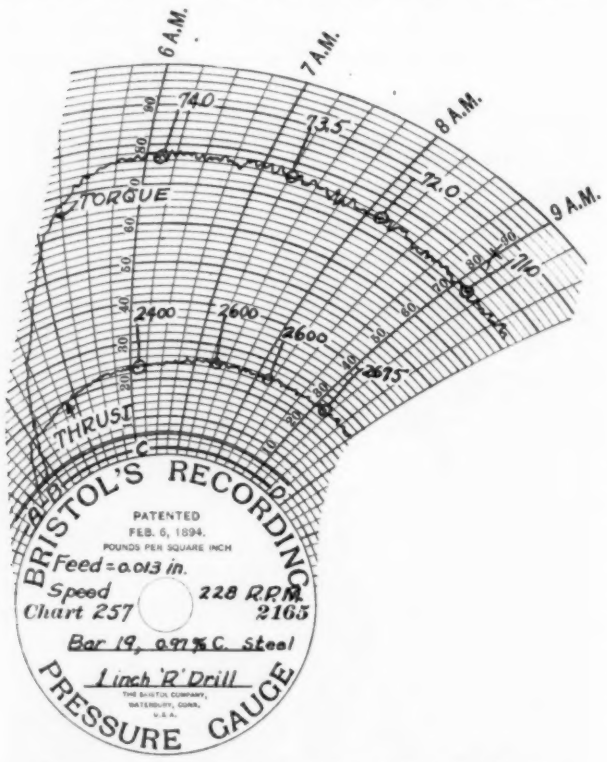


FIG. 3 TYPICAL DRILL TORQUE-AND-THRUST CHART

Mercury-gage reading = 74 to 72
Tight-pulley speed = 618
Actual r.p.m. = 228 × 618/625 = 225.5
Average of four torque readings = 72.63 ft-lb.
Average of four thrust readings = 2569 lb.

from the upper end of the spindle over pulleys to a position vertically above the gage, thence downward, making one turn about a special pulley on the shaft of the gage which carried the chart, to the counterweight shown below the gage.

In calibrating the mercury column and gage for torque in foot-pounds, a couple was applied to the bed of the dynamometer as follows: A 2 in. × 4 in. wood bar was clamped in the vise of the table dynamometer in place of the material to be drilled. This bar extended four feet either way from the center of the drill spindle. Load increments of $^1/_4$ lb. were applied at each end. These loads were suspended by cords over radial ball bearings, so as to transfer the vertical load to one horizontal and at right angles to the ends of the bar. Both horizontal forces acted in a clockwise direction.

Load increments, equivalent to two foot-pounds, were successively added to each end of the bar and corresponding marks, indicating the torque in foot-pounds applied to the dynamometer, were simultaneously made on the mercury-column gage and the recording gage, in order to secure the complete graduated range desired. These marks were made both on increasing and reducing increments of load, so as to allow for any friction which might exist. During this calibration, the spindle of the press was rotated idly by the motor to furnish a slight vibration which would tend to eliminate any friction which might exist in the ball bearings or other parts of the dynamometer. The value of this vibration, however, is somewhat questionable. Various vertical loads up to 3000 lb. were also applied to the dynamometer table during this calibration, but seemed to show no influence on the torque.

The calibration of the recording gage for thrust was obtained by applying various known vertical loads to the spindle. These loads were transmitted through a steel loop-spring placed between the end of the spindle and the table of the dynamometer. The loop spring was supported on knife edges placed in the center of the longer sides. This spring was provided with a dial gage placed across its minor axis so that the load imposed on it could be measured as a function of the deflection. The spring and gage had previously been calibrated on a Reihle universal testing machine. (See Trans. A.S.M.E., 1926, page 755.) As the load was increased by 500-lb. increments corresponding marks were made on the gage chart. After a sufficient number of marks were made on the dial-gage chart for torque and thrust, celluloid scales for torque and thrust were prepared, having the same and smaller graduations. The scale for torque measured $1^5/_8$ in. between the zero and 50-ft-lb. marks, and $3^3/_{16}$ in. between the zero and 90-ft-lb. marks. The thrust scale measured $^{21}/_{32}$ in. between the zero and the 2000-lb. marks, and $^{63}/_{64}$ in. between the zero and the 3000-lb. marks.

Fig. 3 shows a section of a torque and thrust chart from the tests. This is for a one-inch diameter drill cutting tool steel bar 19, at a feed of 0.013 in. and a set-up speed of 228 r.p.m., but an actual speed of 225.5 r.p.m.

After the drill press has been properly set up with the drill and the appropriate speed and feed, the material is adjusted in the vise of the dynamometer. The mercury-column gage is next adjusted for zero reading. At this point, the chart of the pressure gage is rotated so as to draw the base lines for the torque and thrust pens. This insures having the same torque zero reading in all tests, and the exact torque and thrust base lines for each individual test. The drill is brought to within $^3/_8$ in. from the surface of the work to be drilled, after which the feed clutch is engaged. The motor is next started and the belt shifted from the loose pulley to the tight pulley. The drill is thereby rotated and fed toward the work through the $^3/_8$ in. travel, without cutting. During this time the wattmeter is recording the power developed by the motor in driving the machine with all speed and feed gears engaged, but not cutting. At the point A in Fig. 3 the drill has made contact with the work, as is indicated by the increase in the thrust curve. There is no appreciable increase in torque until the drill has penetrated the material to the point B shown on the chart. This distance varies with the drill size. The torque and thrust have reached their full value only when the drill has penetrated to the radial line C shown on the chart. A hole $1^1/_2$ in. deep is drilled between the radial lines C and D. The celluloid scale is used to measure the value of the torque from the base line at four points along the curve of uniform torque. The thrust is similarly measured at four corresponding points. During the drilling, the actual rotating speed of the tight-pulley shaft is measured with a cut-meter, in order that proper allowance may be made for belt slippage, reduced speed of the motor, etc. The nominal speed of the tight-pulley shaft is 625 r.p.m. The motor pulley was made slightly over size, however, so that under no load the tight-pulley shaft rotated at 634 r.p.m. The actual speed of the drill is obtained by multiplying the set-up speed of the drill, by a factor equal to the actual speed divided by the nominal speed, as indicated in Fig. 3, where the average torque, thrust, and r.p.m. developed by the drill are recorded.

The output at the drill point equals the horsepower due to the torque plus that due to the thrust, as follows:

$$\text{output horsepower} = \frac{2\pi \times 72.63 \times 225.5}{33{,}000} + \frac{2569 \times 225.5 \times 0.013}{12 \times 33{,}000} = 3.118 + 0.01905 = 3.13705.$$

The power input to the drill press was determined by attaching to the power line a model LR, AC, S-Polyphase, 60 cycle, 220 volts, clock 73-R, movement 230-p, Esterline-Angus wattmeter. Before use, the wattmeter was carefully calibrated so that the true load in kilowatts developed by the motor could be correlated accurately with the displacement of the pen on the wattmeter chart. The wattmeter chart, paper No. 2310½ C, was two units wide. Each unit was subdivided into tenths of a unit. In order that the calibration made on this paper would be maintained if any other paper were used, a scale was made on cardboard numbered from zero, by tenths, to 2.0, corresponding exactly with the lines of the chart on which the calibration was made. (See Fig. 4.) This cardboard scale was then used to determine the tenths of units deflection of the wattmeter pen on the various wattmeter test charts. The tenths of units were then converted into the true load in kilowatts developed by the motor by another chart which had tenths as abscissas and the kilowatt readings as ordinates with a line drawn from the origin at an angle of approximately 45 deg., in accordance with the calibration.

Fig. 4 shows the chart from the wattmeter as recorded at the time the torque-and-thrust chart was made. The motor is started at C and the belt is thrown from the loose to the tight pulley so that the chart reading at A represents the power developed by the motor in running the press idly during the ³/₈-in. drill travel, before starting to cut. This is called the tare reading. When the drill starts to cut, the power increases, and an average value is taken at B. Below the chart in Fig. 4 is shown the scale used for obtaining the readings from the wattmeter charts.

The gross power equals XB = 0.70 unit = 3.67 kw.
The tare power equals XA = 0.09 unit = 0.502 kw.
The net power equals AB = 3.670 — 0.502 = 3.168 kw. = 4.245 hp.

From the torque-and-thrust values of Fig. 3, the power output was found to be 3.137 hp., and from the wattmeter chart of Fig. 4 the net input was found to be 4.245 hp. The efficiency, then, with the particular gears used is 3.137 divided by 4.245 = 74.8 per cent. This efficiency indicates the difference in friction in the various parts of the mechanism when running idly and under power. This efficiency will vary slightly, for the different ratios of pick-off speed and feed gears, and the ratio of the back gears used. The efficiency of the operation considering the total or gross input of 3.67 kw. or 4.918 hp. is 63.8 per cent.

Speeds and Feeds Used

The feeds used were selected from the tables of speeds and feeds for high-speed-steel drills, on page 233 of the National Twist Drill and Tool Company, catalog No. 14. The values selected, as shown in Table 5, compare favorably with those given in most other tables of this type, and are believed to represent good practice, based on years of experience. The feeds as given had to be modified in some instances because those specified were not available through the change gears of the drill press used in the experiments, so that the nearest feed available was substituted. It is realized that in some plants, or individual operations, lower feeds with speeds above normal are used. Again, feeds heavier than those specified may be used with speeds above or below those recommended by common practice to suit various requirements or conditions, such as the finish or accuracy of alignment required, the depth of the hole to be drilled, the material being drilled, the kind of cutting fluid used, if any, the kind and condition of the drilling machine, etc. To anticipate such variations over a limited range, a series of tests were first run with the ¹/₄-, 1-, and 1¹/₄-in. diameter drills in steel and cast iron, with feeds ranging from 0.006 to 0.021 in. per revolution for each drill size and material.

It was originally the intention of the authors to run tests as near as possible to those specified for each material in the usual speed and feed table. It was obvious that with the larger drills and their heavy feeds, the power would be so much larger than for small drills, that different rheostat settings for the wattmeter would have to be used in order to get charts on the same scale large enough to read without serious error for the small power values, and yet not too large for the large values. From preliminary tests made to determine the influence of speed on the torque and thrust, it was concluded that while power increased in direct proportion to the speed, the torque and thrust were each quite constant for a given drill diameter and feed, over the whole range of speeds available. Also, the five horsepower motor attached to the drill press used in these experiments, did not have sufficient capacity to drive the larger drills with their corresponding heavy feeds at appropriate commercial speeds.

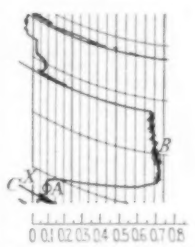


Fig. 4 Wattmeter Chart Corresponding to the Torque-and-Thrust Chart Shown in Fig. 3

Knowing the torque, thrust, and feed for any test, the power output at the drill point can be determined readily for any desired speed. By dividing its calculated net-power-output by the efficiency of the motor and press, the input is obtained. For commercial tests, therefore, a cutting speed of 60 ft. per min. was selected. The r.p.m. for the surface speed of 60 ft. per min. for each drill size, and the r.p.m. for which speed gears were available as near these values as possible, are given in Table 5. In every test, the actual speed was observed by the cut meter, so as to account for belt slippage in the final calculations of power developed at the point of the drill.

A coolant was used in all of the tests, which consisted of one part of soluble oil to 16 parts of water. This was renewed frequently during the tests so that its properties would remain as constant as possible.

Results of Tests

The experiments run to determine the power required to drill cast iron and steel were conducted under two main headings: commercial and special. The commercial tests were conducted so as to determine the torque, thrust, horsepower input and output for each drill diameter operating at a peripheral speed of 60 ft. per min., and at a feed which is considered good for commercial practice. The speeds and feeds for the various drills are given in Table 5. The second set of experiments under the heading of special tests were run to determine the influence of each particular variable such as the drill size, feed, and speed, in the hopes that satisfactory values might be determined for the torque, thrust, or power developed for any drill diameter at any speed and feed.

The Commercial Drilling Test

A summary of the data obtained in drilling bar 3, S.A.E. 2320 steel, with all available drill sizes at a speed of approximately

60 ft. per min. and the commercial feeds, is given in Table 6. The average torque in foot-pounds is recorded for each drill size and feed together with its equivalent in computed horsepower. The thrust for each drill size and feed is also given, together with its computed horsepower for the speed and feed recorded. The total horsepower output developed at the drill point, which equals the horsepower due to the torque plus that due to the thrust, is shown. The net input developed by the motor is shown in both kilowatts and equivalent horsepower. This net input equals the gross power developed minus the tare or that power developed by the motor to drive the drill press with the speed and feed gears engaged, but with the drill not cutting. Finally, the efficiency of the press is shown and is

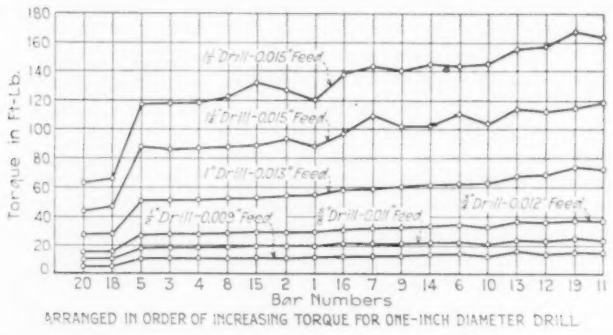


FIG. 5 TORQUE VALUES FOR EACH DRILL DIAMETER AND ITS COMMERCIAL FEED FOR ALL MATERIALS

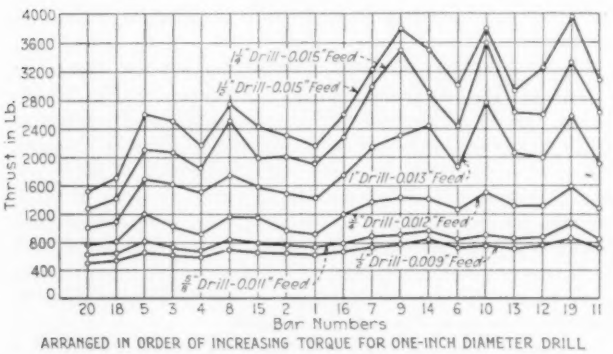


FIG. 6 THRUST VALUES FOR EACH DRILL DIAMETER AND ITS COMMERCIAL FEED FOR ALL MATERIALS

as of the loads carried by them. The fact that these efficiencies do not vary uniformly from the maximum for the smallest drill, to the minimum for the largest drill, is believed to be due to the ratio of the speed and feed change gears, and the ratio of the back gears used for each particular test.

Figs. 5, 6, and 7 show the torque, thrust, and net horsepower input values, respectively, plotted over the bar numbers arranged in order of increasing torque for the 1-in. diameter drill. The torque values as shown in Fig. 5 for each drill size and commerical feed indicated an increase, in general, from the left to the right, following the 1-in. drill torque curve rather satisfactorily. The values for bar 10, for the $^1/_2$-, $^5/_8$-, $^3/_4$-, and $1^1/_4$-in. diameter drills are low, however, and indicate that bar 10 properly belongs farther to the left. Also, the values for the $1^1/_4$-in. and $1^1/_2$-in. drills appear to vary more than those for the other drill sizes; the values for bar 1 are particularly low for the two largest drills. No explanation can be given for such irregularities unless they are due to variations in the properties of the material at the particular points drilled.

The thrust values, as shown in Fig. 6, vary considerably more throughout each curve than the torque values do. This variation is believed to be the result of differences in the material,

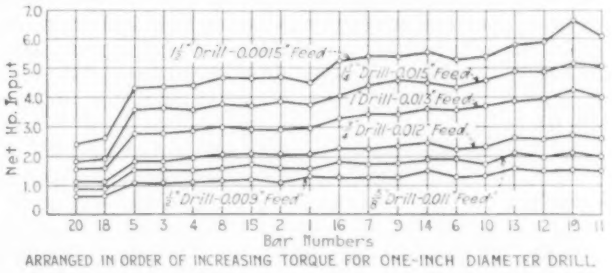


FIG. 7 NET HORSEPOWER INPUT VALUES FOR EACH DRILL DIAMETER AND ITS COMMERCIAL FEED FOR ALL MATERIALS

or due to the variation in the length of the chisel edge of the drill as the web thickness increases through repeated grinds. This increase in web thickness, from that of the new drill to that after the last grind is shown in Table 2, and is greatest for the largest drills. This total variation, however, did not occur during the running of these commercial tests, and so can be held responsible for only a small share. While the variation in the thrust curves is disconcerting when the loads on the drill or spindle bearings and gears are concerned, it is of little importance as far as power is concerned, inasmuch as the thrust by itself contributes less than 1 to 2 per cent of the total computed power.

TABLE 6 SUMMARY OF RESULTS OF THE COMMERCIAL DRILLING TESTS FOR ALL DRILL SIZES ON BAR 3 STEEL S.A.E. 2320

Drill size	R.p.m. Set-up	R.p.m. Factor	R.p.m. Actual	Feed, in. per rev.	Torque in ft-pounds	Torque hp. = 0.0001904 $N\,T$	Thrust in lb.	Thrust hp. = $\frac{F\,Th\,N}{12\times33{,}000}$	Total hp. output = hp.T + hp.Th	Input net gross-tare Kw.	Input net gross-tare Hp.	Eff. = $\frac{\text{hp.(out)}}{\text{hp.(in.)}}$
$^1/_2$	441	$\frac{633}{625}$	446	0.009	11.0	0.934	618.75	0.00627	0.9403	0.790	1.058	88.8
$^5/_8$	360	$\frac{639}{625}$	368	0.011	18.7	1.311	728.75	0.00745	1.3185	1.19	1.595	82.7
$^3/_4$	296	$\frac{630}{625}$	298.3	0.012	27.7	1.574	1027.25	0.00928	1.5833	1.37	1.838	86.1
1	228	$\frac{624}{625}$	227.6	0.013	51.3	2.223	1615.6	0.01208	2.2351	2.07	2.774	80.6
$1^1/_4$	178	$\frac{618}{625}$	176	0.015	86.1	2.883	2058.3	0.01372	2.8967	2.72	3.642	79.6
$1^1/_2$	153	$\frac{618}{625}$	151.2	0.015	118	3.40	2506.25	0.01434	3.543	3.254	4.36	81.3

equal to the computed horsepower output divided by the horsepower input. As is usual in all of these tests, the efficiency is highest for the smallest drill rotating at the greatest r.p.m., and is lowest for the largest drill which rotates at the slowest r.p.m. It appears, therefore, that the efficiency is not so much the function of the speed at which the gears and bearings rotate

The net horsepower input values for each drill diameter operating at its commercial feed and a speed of approximately 60 ft. per min. are shown in Fig. 7. This net horsepower was determined from the wattmeter charts, and is the equivalent of

the gross power minus the tare. The tare value varies considerably for the different speeds used, and is much greater for the $^1/_2$-in. drill than for the $1^1/_2$-in. drill. The influence of the different feed gears used, however, is hardly perceptible, as the rise in the curve when the feed gears are engaged is not more than the thickness of the line on the chart. It was, therefore, thought desirable to present these net values rather than the gross values as they may be compared directly. These input values follow quite satisfactorily the general trend of the torque curves shown in Fig. 5.

The complete drilling story for the commercial drilling tests on six materials, bars 20, 5, 1, 7, 10, and 19, selected at random throughout the material range, are shown in Figs. 8 to 13, inclusive. Fig. 8, for example, shows for bar 20, cast iron containing 20 per cent charcoal pig, the torque in foot-pounds, the thrust in pounds, the net power input in horsepower determined from the wattmeter chart, and the computed horsepower output at the drill point for each size at its appropriate speed and feed shown in Table 5.

It should be noted that the abscissas consist of two variables, the drill diameter and the feed, so that there is no particular reason why these torque or thrust curves should be smooth curves. From the $^1/_2$-in. drill to the $^5/_8$-in. drill, the diameter increment is $^1/_8$ in., while the feed increment is 0.002 in. For the $^1/_8$-in. diameter increment between the $^5/_8$-in. and $^3/_4$-in. drills, the feed increase is only 0.001 in. For the $^1/_4$-in. increase in diameter between the $^3/_4$-in. drill and 1-in. drill, the feed increase is only 0.001 in. The $1^1/_4$-in. and $1^1/_2$-in. drills operate at the same feed.

The torque, thrust, input, and output horsepower curves are shown for bar 5, S.A.E. 3135 steel, in Fig. 9. The general characteristics of the curves are similar to those of Fig. 8 for cast iron. In Fig. 8 the thrust value for the $1^1/_4$-in. diameter drill appears to be somewhat low in order to obtain a smooth curve concave downward. In Fig. 9 the thrust values for the $^5/_8$-in. drill appear to be a little low for a similar curve concave downward. The torque curves in Figs. 8 to 13, inclusive, appear to be rather smooth curves slightly concave upward. In all

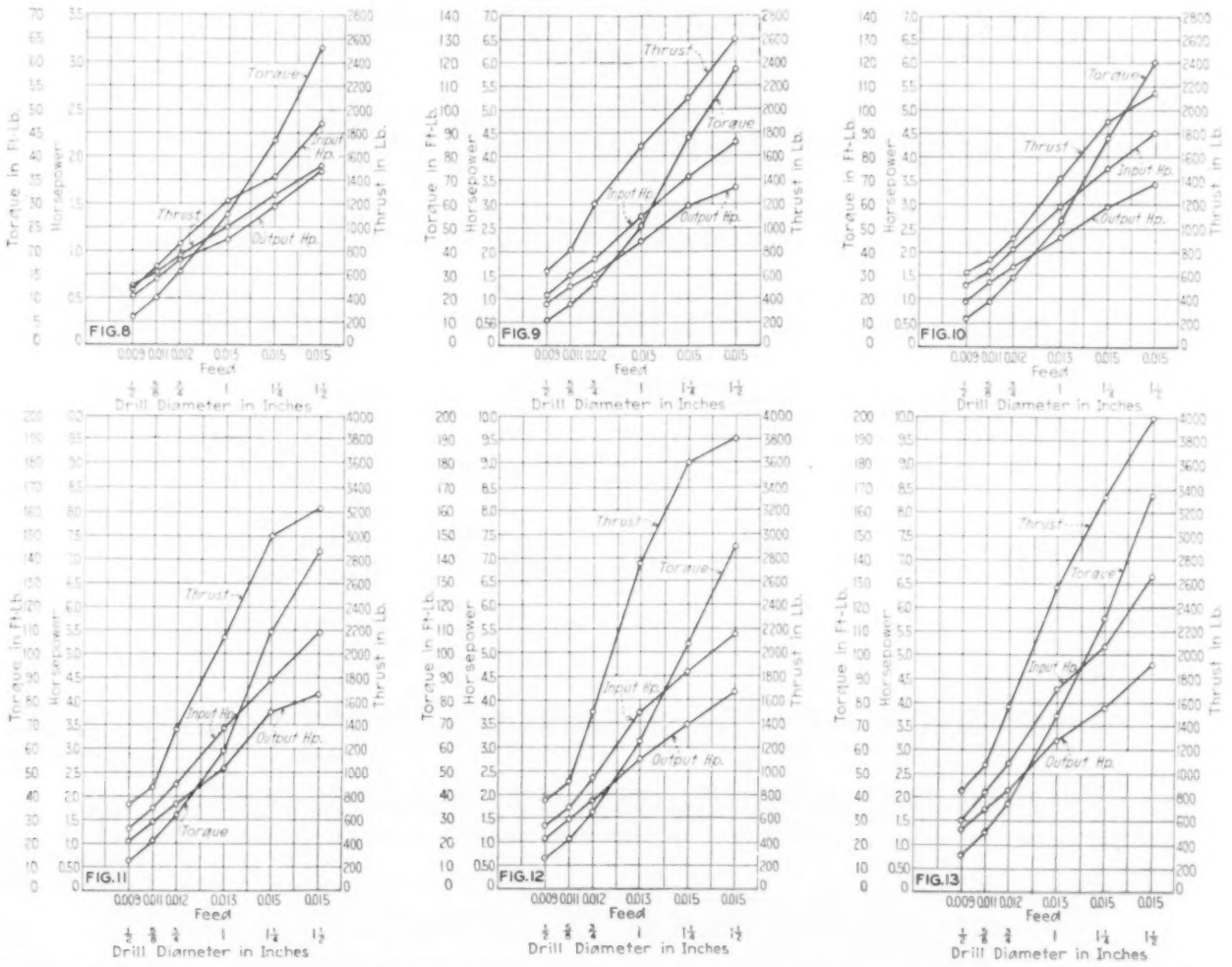


FIG. 8 COMMERCIAL DRILLING TESTS ON BAR 20 (20 PER CENT CHARCOAL) SHOWING TORQUE, THRUST, NET-POWER INPUT AND OUTPUT

FIG. 9 COMMERCIAL DRILLING TESTS ON BAR 5 (S.A.E. 3135) SHOWING TORQUE, THRUST, NET-POWER INPUT AND OUTPUT

FIG. 10 COMMERCIAL DRILLING TESTS ON BAR 1 (S.A.E. 1020) SHOWING TORQUE, THRUST, NET-POWER INPUT AND OUTPUT

FIG. 11 COMMERCIAL DRILLING TESTS ON BAR 7 (S.A.E. 3250) SHOWING TORQUE, THRUST, NET-POWER INPUT AND OUTPUT

FIG. 12 COMMERCIAL DRILLING TESTS ON BAR 10 (S.A.E. 2340) SHOWING TORQUE, THRUST, NET-POWER INPUT AND OUTPUT

FIG. 13 COMMERCIAL DRILLING TEST ON BAR 19 (S.A.E. 1095) SHOWING TORQUE, THRUST, NET-POWER INPUT AND OUTPUT

the illustrations there is a constantly increasing divergence from the left to the right between the recorded input and the computed output horsepower curves, which is as might be expected.

While Figs. 8 to 13, inclusive, show graphically the specific torque, thrust, and power values for six selected materials, the results of the commercial tests for all materials are shown in Table 7.

TABLE 7 DRILLING DATA SUMMARIZED FROM COMMERCIAL TESTS

Bar No.	Material Type	Drill size and feed in in. per rev.	Actual r.p.m.	Torque in ft.-lb.	Thrust in lb.	Computed hp. output	Net hp. input	Bar No.	Material Type	Drill size and feed in in. per rev.	Actual r.p.m.	Torque in ft.-lb.	Thrust in lb.	Computed hp. output	Net hp. input
18	Cast iron	1/2 × 0.009	446	6.3	530	0.5411	0.6300	9	S.A.E. 2330 Steel	1/2 × 0.009	445	12.6	776	1.0758	1.267
		5/8 × 0.011	364.4	10.2	645	0.7145	0.864			5/8 × 0.011	371.2	21.0	910	1.4944	1.756
		3/4 × 0.012	299.7	15.7	803	0.9033	1.126			3/4 × 0.012	298.3	32.35	1425	1.8519	2.373
		1 × 0.013	229.8	27.9	1087.5	1.2292	1.568			1 × 0.013	227.5	60.5	2290.62	2.6371	3.443
		1 1/4 × 0.015	179.4	46.4	1403.125	1.5965	1.943			1 1/4 × 0.015	179.4	101.6	3500	3.4948	4.58
		1 1/2 × 0.015	153.4	65.9	1700	1.9369	2.561			1 1/2 × 0.015	149.8	140	3800	4.0016	5.385
20	Cast iron	1/2 × 0.009	446	6.0	500	0.5141	0.603	10	S.A.E. 2340 Steel	1/2 × 0.009	445	12.7	753.75	1.0856	1.335
		5/8 × 0.011	364.4	10.0	621.25	0.7013	0.838			5/8 × 0.011	370	20.75	903.75	1.4713	1.722
		3/4 × 0.012	301.9	15.6	760	0.9039	1.085			3/4 × 0.012	298.3	32.5	1491.65	1.8625	2.340
		1 × 0.013	229.8	27.7	1006.25	1.2206	1.528			1 × 0.013	227.5	62.5	2758.33	2.7285	3.720
		1 1/4 × 0.015	179.4	43.3	1270.83	1.4887	1.796			1 1/4 × 0.015	174.2	103.4	3600	3.4578	4.380
		1 1/2 × 0.015	153.4	63.0	1517	1.8508	2.354			1 1/2 × 0.015	149.8	145	3800	4.1606	5.390
1	S.A.E. 1020 Steel	1/2 × 0.009	442.5	11.5	626.02	0.9750	1.307	11	S.A.E. 6120 Steel	1/2 × 0.009	445	14.6	712.5	1.2452	1.488
		5/8 × 0.011	368	19.4	732.08	1.3365	1.581			5/8 × 0.011	370	23.18	843.75	1.6417	1.98
		3/4 × 0.012	298.3	29.2	910	1.6692	2.063			3/4 × 0.012	298.3	36.0	1259.3	2.0574	2.615
		1 × 0.013	227.6	54	1415	2.351	2.948			1 × 0.013	224.3	72.0	1900	3.092	3.992
		1 1/4 × 0.015	176	87.9	1900	2.9567	3.75			1 1/4 × 0.015	175.1	118.4	2625	3.9704	5.09
		1 1/2 × 0.015	150.5	120.0	2150	3.4637	4.51			1 1/2 × 0.015	149.5	163	3075	4.657	6.11
2	S.A.E. 1045 Steel	1/2 × 0.009	445.5	11.0	636.8	0.9393	1.105	12	S.A.E. 6130 Steel	1/2 × 0.009	445	14.1	760.02	1.2037	1.495
		5/8 × 0.011	368	19.6	762.5	1.381	1.581			5/8 × 0.011	363.0	23.1	875	1.6058	1.978
		3/4 × 0.012	298.3	29.1	959	1.658	2.022			3/4 × 0.012	298.3	36.0	1315	2.0579	2.576
		1 × 0.013	227.5	54.0	1490	2.45	2.988			1 × 0.013	227.5	68.5	1993.75	2.9869	3.94
		1 1/4 × 0.015	176	93.0	2000	3.129	3.7			1 1/4 × 0.015	176	112.0	2600	3.7753	4.87
		1 1/2 × 0.015	150.5	127.0	2300	3.770	4.66			1 1/2 × 0.015	147.6	157.2	3243.05	4.438	5.93
3	S.A.E. 2320 Steel	1/2 × 0.009	446	11.0	618.75	0.9403	1.058	13	S.A.E. 6140 Steel	1/2 × 0.009	445	15.5	712.5	1.3212	1.562
		5/8 × 0.011	368	18.7	728.75	1.3185	1.595			5/8 × 0.011	362	23.4	856	1.6226	2.086
		3/4 × 0.012	298.3	27.7	1027.25	1.5833	1.838			3/4 × 0.012	298.3	36.6	1316.8	2.0919	2.621
		1 × 0.013	227.6	51.3	1615.6	2.2351	2.774			1 × 0.013	226.5	67.8	2048.12	2.9382	3.867
		1 1/4 × 0.015	176	86.1	2058.3	2.8967	3.642			1 1/4 × 0.015	179.4	114.0	2627.5	3.9169	4.865
		1 1/2 × 0.015	151.2	118.0	2506.25	3.543	4.36			1 1/2 × 0.015	147.6	155.0	2934	4.3764	5.81
4	S.A.E. 3120 Steel	1/2 × 0.009	446	11.0	571.875	0.9398	1.126	14	S.A.E. 9250 Steel	1/2 × 0.009	445	13.7	836.8	1.1715	1.515
		5/8 × 0.011	368	18.6	673.75	1.3109	1.48			5/8 × 0.011	362	21.6	960	1.4987	1.877
		3/4 × 0.012	298	27.9	912.5	1.5912	1.943			3/4 × 0.012	298	32.9	1400.4	1.8806	2.445
		1 × 0.013	227.6	51.3	1500	2.2332	2.847			1 × 0.013	226.5	61.2	2432.29	2.6591	3.592
		1 1/4 × 0.015	176	87.0	1838.75	2.9313	3.59			1 1/4 × 0.015	176	102.6	2900	3.4583	4.51
		1 1/2 × 0.015	151.2	118.4	2155	3.4254	4.39			1 1/2 × 0.015	149.8	144.4	3500	4.1449	5.57
5	S.A.E. 3135	1/2 × 0.009	446	10.4	647	0.8896	1.058	15	Cr-Mo	1/2 × 0.009	445	11.3	646.6	0.9645	1.192
		5/8 × 0.011	371.2	17.5	813.125	1.2464	1.514			5/8 × 0.011	363	19.6	786.875	1.3629	1.689
		3/4 × 0.012	298.0	26.3	1200	1.5028	1.823			3/4 × 0.012	299.7	28.9	1153.125	1.6595	2.086
		1 × 0.013	227.6	50.8	1683	2.2126	2.747			1 × 0.013	227.0	53.1	1574.6	2.3097	2.881
		1 1/4 × 0.015	176	88.0	2100	2.964	3.58			1 1/4 × 0.015	176	89.0	1987.5	2.9953	3.683
		1 1/2 × 0.015	151	117.0	2600	3.3849	4.285			1 1/2 × 0.015	149.8	132.0	2433.3	3.7848	4.842
6	S.A.E. 6150 Steel	1/2 × 0.009	444.5	14.0	725	1.1933	1.259	16	Cr-Mo	1/2 × 0.009	445	11.9	670	1.0158	1.273
		5/8 × 0.011	368	22.3	838.05	1.5706	1.877			5/8 × 0.011	363	21.1	792.5	1.467	1.79
		3/4 × 0.012	299.7	34.3	1269	1.9695	2.2346			3/4 × 0.012	299.7	30.8	1190	1.7688	2.263
		1 × 0.013	228.1	62.4	1862	2.7239	3.55			1 × 0.013	227.5	59.0	1737.5	2.571	3.282
		1 1/4 × 0.015	175.1	110.8	2430	3.7151	4.37			1 1/4 × 0.015	176	96.5	2278.125	3.2512	4.045
		1 1/2 × 0.015	149	143.3	3000	4.0869	5.32			1 1/2 × 0.015	149.8	137.7	2600	3.9488	6.255
7	S.A.E. 3250 Steel	1/2 × 0.009	445	12.4	728.25	1.0584	1.287	19	S.A.E. 1095 Steel	1/2 × 0.009	445	15.37	852	1.3106	1.501
		5/8 × 0.011	369	20.55	875	1.452	1.742			5/8 × 0.011	363	24.8	1067	1.7248	2.106
		3/4 × 0.012	298.3	31.9	1363	1.8253	2.253			3/4 × 0.012	298.3	37.4	1565.625	2.1389	2.708
		1 × 0.013	227.5	59.0	2137.5	2.57	3.419			1 × 0.013	225.4	74.0	2575	3.1921	4.275
		1 1/4 × 0.015	179.4	109.4	2988	3.7604	4.425			1 1/4 × 0.015	176	114.8	3327.0	3.8642	5.162
		1 1/2 × 0.015	150.5	143.12	3225	4.1284	5.440			1 1/2 × 0.015	149.5	167.2	3983.3	4.7826	6.638
8	S.A.E. 3140 Steel	1/2 × 0.009	446	10.9	693.1	0.933	1.152								
		5/8 × 0.011	369	18.8	831.25	1.3305	1.582								
		3/4 × 0.012	298.3	28.0	1152	1.605	2.024								
		1 × 0.013	227.5	52.4	1741.6	2.286	2.989								
		1 1/4 × 0.015	176	88.0	2474.5	2.968	3.7								
		1 1/2 × 0.015	150.5	122.3	2740	3.5256	4.66								

The Special Drilling Tests

In order to throw more light on the influence of the drill diameter, the feed in inches per revolution, and the speed of rotation, a number of special tests were run in which but one of these factors was varied at a time. It was hoped that by knowing the influence of each one of these variables, the data from the commercial tests as presented in Figs. 5 to 13, inclusive, and Table 7, could be extended to cover almost any combination of drill diameter, speed, and feed. The tests were run with a soluble oil mixed with 16 parts of water; the same as used in the commercial tests.

Variable Speed Tests were run with speeds of 74, 153, 230, 296, 360, and 441 r.p.m. on steel and cast iron with $^1/_2$-, 1-, and $1^1/_4$-in. diameter drills at a feed in each case of 0.012 in. In Fig. 14 are given the results of the tests with the six different speeds ranging from 74 to 441 r.p.m. for a $^1/_2$-in. diameter drill on bar 6, S.A.E. 6150 steel, and a cast-iron bar 20 (20 per cent charcoal pig, dated 4–8–28), not listed in Table 1 but similar to bar 18. The feed for the $^1/_2$-in. drill was 0.012 in. per revolution. The torque for steel, shown in solid lines, is practically constant at $17^1/_2$ foot-pounds for speeds of 441, 360, and 296

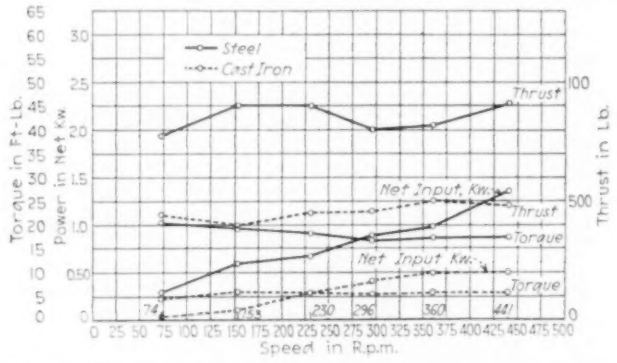


Fig. 14 Variable-Speed Tests Showing Torque, Thrust, and Net-Input Kilowatts for Steel Bar 6 (S.A.E. 6150) and Cast-Iron Bar 20, 4–8–28 (20 Per Cent Charcoal Pig) With Constant Feed of 0.012 Inch per Revolution—Diameter of Drill $^1/_2$ Inch "R"

r.p.m., but then increases gradually to 20 foot-pounds when the speed is reduced to 74 r.p.m. The torque values for cast iron, shown in dashed lines, are practically constant at 6.3 foot-pounds at all speeds except 74 for which the torque is only 4.5 foot-pounds. It is also to be seen that the torque for the steel is 2.78 times that for the cast iron. From these data, it may be concluded that the torque is not a function of the revolutions of the drill, but is constant over the range covered.

The thrust curves for both the cast iron and steel vary slightly for different speeds. This variation is thought to be due to the material, or condition of the drill, rather than to the variation in speed. The input in kilowatts for both the steel and cast iron as determined by the wattmeter also appears to be a straight-line function, although some points do not fall exactly on this straight line. In all cases exact experimental results are shown rather than smoothed-out values.

Variable-speed tests for the 1-in. diameter drill at a constant feed of 0.012 in. per revolution for steel bar 6 and cast-iron bar 20 (4–8–28), are shown in Fig. 15. The materials are the same as those used in the tests reported in Fig. 14. The torque curve for steel appears to be horizontal except for the high value of 63 foot-pounds at the lowest speed of 74 r.p.m. This was checked three times and the same values obtained each time. The other values, however, appear to be practically constant at about 58.5 foot-pounds. The torque curve for cast iron appears to be practically horizontal, i.e., at 25 foot-pounds for the intermediate speeds, but slightly low for the lowest and highest speeds. The thrust values for both the cast iron and steel appear to be such that, allowing for the slight variations due to

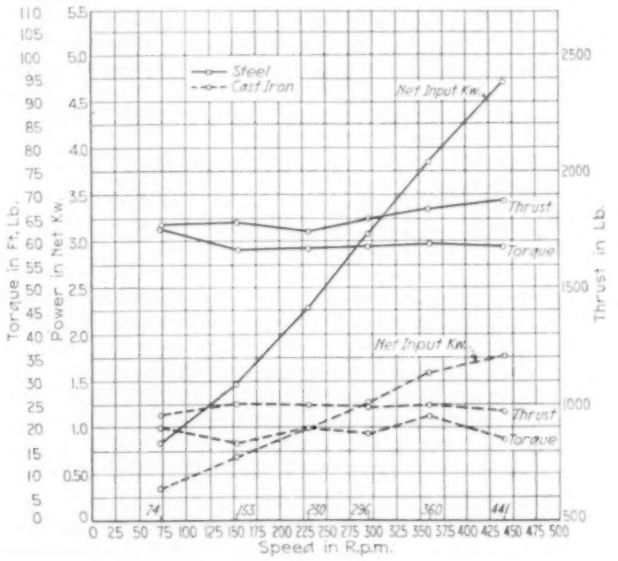


Fig. 15 Variable-Speed Tests Showing Torque, Thrust, and Net-Input Kilowatts for Steel Bar 6 (S.A.E. 6150) and Cast-Iron Bar 20, 4–8–28 (20 Per Cent Charcoal Pig) With Constant Feed of 0.012 Inch per Revolution—Diameter of Drill One Inch "R"

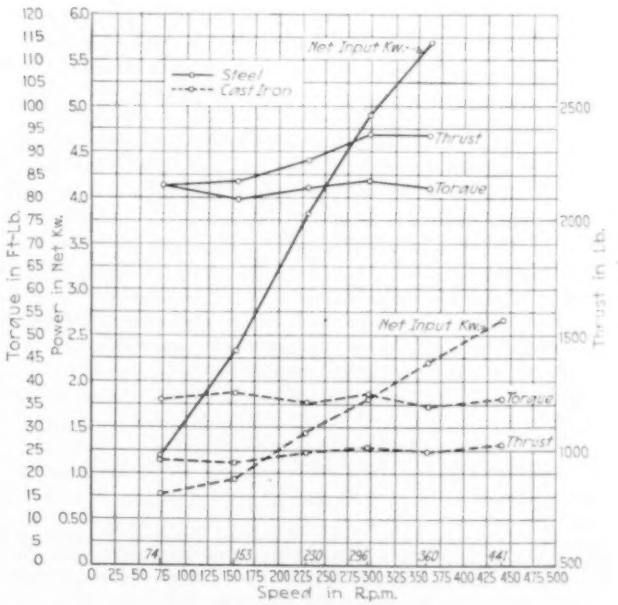


Fig. 16 Variable-Speed Tests Showing Torque, Thrust, and Net-Input Kilowatts for Steel Bar IIIIII (0.15 Per Cent C) and Cast-Iron Bar 25, 4–8–28 (20 Per Cent Charcoal Pig) With Constant Feed of 0.012 Inch per Revolution-Diameter of Drill $1^1/_4$ Inch "R"

experimental error and variation in material, it may be concluded that the thrust is not a function of the speed but constant over the whole range of speeds covered. The net input in kilowatts as determined by the wattmeter appears to vary directly with the speed.

Fig. 16 shows another series of tests on a 0.15 per cent carbon open-hearth steel bar IIIIII, and cast-iron bar 25 (20 per cent charcoal pig dated 4–28–8) for a drill diameter of $1^1/_4$ in. and a feed of 0.012 in. per revolution. The torque values for both the cast iron and steel are practically constant over the whole speed range. The thrust values for cast iron are practically constant, but those for steel appear to increase from 2150 lb. at 74 r.p.m. to 2370 lb. for 360 r.p.m. This increase, while uniform, would

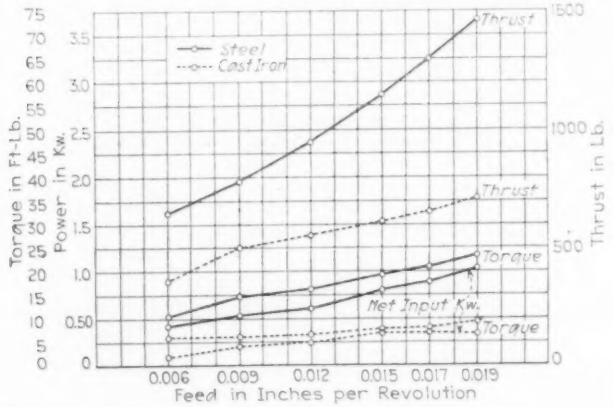


Fig. 17 Variable-Feed Tests Showing Torque, Thrust, and Input Kilowatts for Steel Bar 6 (S.A.E. 6150) and Cast-Iron Bar 20 (20 Per Cent Charcoal Pig) With Constant Speed of 230 R.p.m.—Diameter of Drill $^1/_2$ Inch "R"

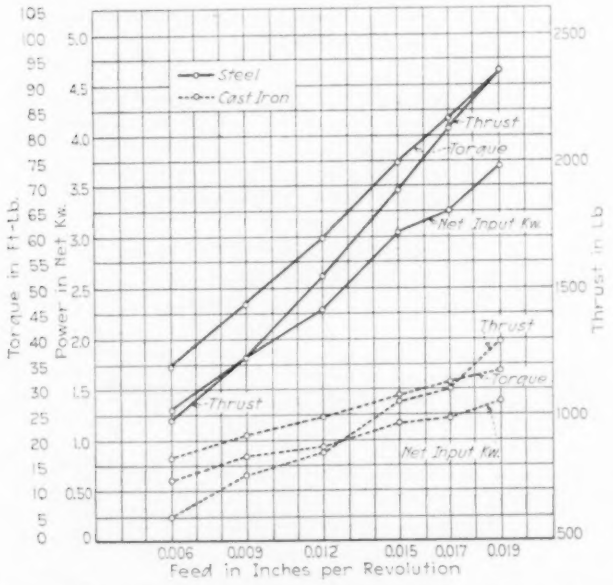


Fig. 18 Variable-Feed Tests Showing Torque, Thrust, and Net Input Kilowatts for Steel Bar 6 (S.A.E. 6150) and Cast-Iron Bar 20 (20 Per Cent Charcoal Pig) With Constant Speed of 230 R.p.m.—Diameter of Drill One Inch "R"

indicate that the thrust increases with the speed. In view of the slight increase, however, and the results of the previous tests, it is concluded that the thrust is practically constant over the whole speed range.

Variable Speed Tests—Results of Other Experimenters

Benedict and Lukens[4] conclude that when drilling cast iron with a 1-in. diameter drill having a clearance of 7 deg. and a point angle of 118 deg., the torque decreases as the speed increases for a given feed per revolution, although in most cases no decrease in torque appears for speeds greater than 400 r.p.m. The results are not uniform for speeds less than 150 r.p.m. In nearly all tests this decrease in torque was noted, particularly when the drill was a trifle dull. Eight feeds from 0.00364 to 0.041 in. per revolution were used. An analysis of these curves indicates that for all feeds of 0.0256 in. and less, the torque curve is really horizontal for speeds of 570 r.p.m. down to 200, and again horizontal but slightly higher for speeds of 150 r.p.m. down to 60 r.p.m. For the feed of 0.041 in. the torque curve is smooth, and decreases quite uniformly as the speed is increased. The thrust values from these same tests by Benedict show the

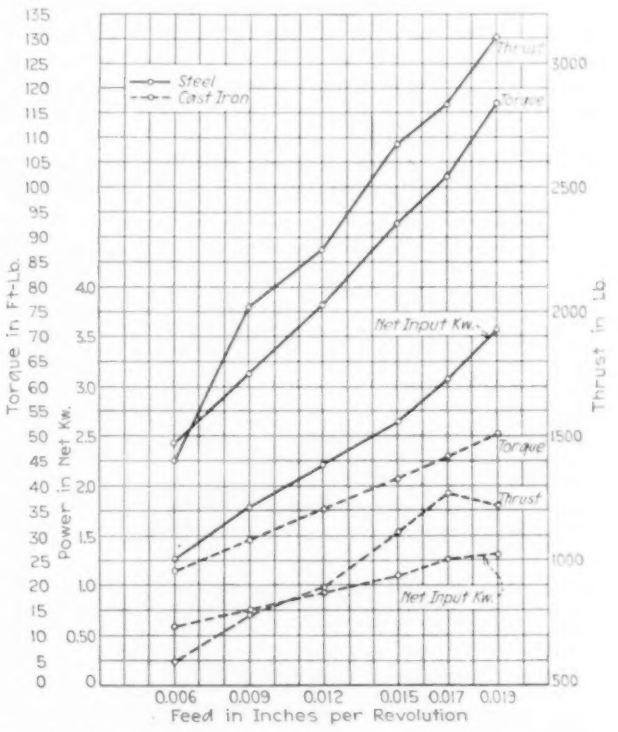


Fig. 19 Variable-Feed Tests Showing Torque, Thrust, and Net Input Kilowatts for Steel Bar IIIIII (0.15 Per Cent C) and Cast-Iron Bar 25 (20 Per Cent Charcoal Pig) With Constant Speed of 153 R.p.m.—Diameter of Drill $1^1/_4$ Inch "R"

same general characteristics as for the torque, except that straight lines have been drawn to represent the smooth curve instead of the slightly concave-upward curve for the torque values. The thrust for the feed of 0.00364 in. per revolution is horizontal, but a slope upward to the left for reduced speeds is noticeable for the feed of 0.0056 in. This slope increases with the feed until, for the 0.041 in. per revolution feed, the thrust of 1910 lb. for the speed of 570 r.p.m. is increased 16.6 per cent to 2230 for 60 r.p.m.

H. M. Norris[5] concluded that when the diameter of the drill and rate of feed are constant, the power required to cut a given metal is approximately proportional to the speed.

Bird and Fairfield[6] report that no material difference either in torque or thrust was found by increasing the speed from 140 to 600 r.p.m. when drilling soft gray iron. A $^5/_8$-in. diameter high-speed-steel twist drill was used which had an included point angle of 118 deg.

[4] Ref. 7 in Bibliography, p. 53 and Figs. 32 and 33.

[5] Ref. 2 of Bibliography, p. 75.

[6] Ref. 3 of Bibliography.

Smith and Poliakoff[7] also report that there was no perceptible difference in the torque or thrust with the variation of speed, that is, the net computed horsepower for a given diameter of drill and feed when cutting cast iron or steel is proportional to the revolutions or the cutting speed. Their tests were comprehensive but the speeds were between 5 and 150 r.p.m.

Variable Feed Tests

The results of several tests to show the influence of changing feed on the torque, thrust, and net input in kilowatts for two steels and two cast irons are shown in Figs. 17, 18, and 19. The feeds were varied from 0.006 in. per revolution of the drill to 0.019 in. The results for the $^1/_2$-in. diameter R drill are shown in Fig. 17. The solid lines indicate the thrust, torque, and net input in kilowatts for steel bar 6 (S.A.E. 6150) as reported on in the commercial test, and the dashed lines indicate the values for cast-iron bar 20. (20 per cent charcoal pig, dated 4–8–28.) The speed was constant at 230 r.p.m. The thrust curve for steel shows a steady increase as the feed is increased, and it is slightly concave upward. The curve would have to turn concave downward below the feed of 0.006 in. in order to pass through the origin. This indicates that the thrust curve really should be concave downward all the way rather than as shown. The first 0.006-in. feed from zero gives a thrust of 650 lb. The second 0.006-in. feed (up to 0.012 in.) increases the thrust only 300 lb. to 950 or 46.2 per cent. The third 0.006-in. increase in feed above 0.012 in., causes an increase in thrust of 430 lb. to 1380 lb. for a feed of 0.018 in. In other words, the thrust for a feed of 0.006 in. is 650 lb. while the thrust for 0.018-in. feed is only 1380 lb., or an increase of 112 per cent thrust for the 200 per cent increase in feed. The thrust curve for cast iron, on the other hand, is practically a straight line except for the low value at 0.006-in. feed, which increases in direct proportion to the increase in feed. This curve also would have to continue concave downward to the left in order to pass through the origin, which shows that the thrust for cast iron increases with the feed but at a slower rate. The torque curves for steel and cast iron are also approximately straight lines for the feed range shown, but both would have to turn downward if continued to the left, in order to pass through the origin. The torque value for steel for the feed of 0.009 in. appears to be a little high as is that for cast iron at 0.006-in. feed.

In Fig. 18 are shown the torque, thrust, and net input in kilowatts for the 1-in. R drill rotated at 230 r.p.m. on bar 6, S.A.E. 6150 steel, and cast-iron bar 20. (20 per cent charcoal pig, dated 4–8–28.) Again, the torque curves for both the steel and cast iron are practically straight lines for the range of feeds covered, and both would have to turn downward to the left to pass through the origin. The thrust curves also are practically straight lines, both being slightly concave upward but would have to drop at the left to pass through the origin.

In Fig. 19 are shown the torque, thrust, and net input in kilowatts for steel bar IIIIII (0.15 per cent carbon) and cast-iron bar 25 (20 per cent charcoal pig) for the $1^1/_4$-in. diameter R drill at a constant speed of 153 r.p.m. Again, the two torque curves appear to be practically straight lines for the feed range covered, but are high and would have to turn downward to the left to pass through the origin. The thrust curve for steel is practically a straight line between the feeds of 0.009 and 0.019 in.; the value for the feed of 0.006 in., however, falls below the straight line, and tends to swing the line downward toward the origin. The thrust curve for cast iron is not far from a straight line if the low value for the feed of 0.019 in. is disregarded, but also must turn downward at the left to pass through the origin.

As a conclusion for the influence of the variable feed on the torque and thrust for the $^1/_2$-, 1- and $1^1/_4$-in. diameter drills on steel and cast iron it may be said that the torque on cast iron for all three drill sizes is a straight line, but for steel the torque curve is slightly concave upward for each drill size. It is believed that it should be concave downward. All torque curves must become concave downward if continued to the left in order to pass through the origin. The thrust curves for all three drill sizes on cast iron are straight lines while those on steel are slightly concave upward, except for the $1^1/_4$-in. drill, which is straight. These, too, must turn downward to pass through the origin.

Better to visualize the influence of the feed on the torque and thrust values presented in Figs. 17, 18, and 19 for two steels and two cast irons, the torque and thrust curves were all plotted on log-log paper and their slopes n determined as follows:

For steel bar 6 with the $^1/_2$-in. drill, for bar 6 with the 1-in. drill, and for bar IIIIII with the $1^1/_4$-in. drill, n was found to be 0.722, 0.841, and 0.784, respectively, averaging 0.782, for the torque curves.

For cast-iron bar 20, with the $^1/_2$-in. drill, for bar 20 with the 1-in. drill, and bar 25 with the $1^1/_4$-in. drill, n was found to be 0.547, 0.60, and 0.669, respectively, averaging 0.605 for the torque curves. Similar values of n for the thrust for the steels in the order named above are: 0.809, 0.860, and 0.681, averaging 0.783. The values of n for the thrust curves on the cast iron in the order named were found to be 0.516, 0.580, and 0.710, respectively, averaging 0.602.

It is seen that there is a considerable variation as to the slope of the curves for the same material with different drill sizes, as well as between different materials, so that the variation noted may be due to lack of uniformity in experimental results, or due to the specific material and cutting condition. Not enough information is available to draw definite conclusions on this point at the present time so that the average values will be accepted for the present.

Variable Feed Tests—Results of Other Experimenters

Benedict and Lukens[8] report that "in soft cast iron the torque does not increase so rapidly as the feed per revolution, although variation of torque with feed is so nearly direct that it may for all practical purposes be so considered. For the correct angles of drill grinding, the thrust should increase directly with the feed per revolution. In soft cast iron the torque decreases as the speed increases, although there is little advantage in running a 1-in. drill faster than 450 r.p.m. The saving in power resulting from increasing the speed may amount to 10 or 15 per cent. Thrust decreases as speed increases for corresponding rates of feed, although the advantages to be gained by running a 1-in. diameter drill faster than 400 r.p.m. are slight. The decrease in thrust may amount to 15 per cent."

A 1-in. diameter drill having a clearance of 7 deg. and a point angle of 118 deg. was used on cast iron at feeds ranging from 0.00364 to 0.041 in. per revolution at each of the three speeds of 92, 233, and 456 r.p.m. The torque curves are practically straight lines but slightly concave downward, while the thrust curves are practically straight but slightly concave upward. The torque curves would have to drop sharply at feeds below the smallest used in order to pass through the origin.

Smith and Poliakoff[9] conclude from their extensive experiments that for cast iron the torque does not increase as fast as the feed for any given diameter of drill. Thus, $T = 785\, d^{1.82}\, t^{0.72 - 0.0005d}$ or as a close approximation $T = 740\, d^{1.8}\, t^{0.7}$, in which T = torque in foot-pounds, d = drill diameter in inches, and t = feed in inches per revolution. The following linear

[7] Ref. 4 of Bibliography, Part 1, p. 323 and 378.

[8] Ref. 7 of Bibliography, p. 92, pp. 48–53, Figs. 30 and 31.

[9] Ref. 4 of Bibliography, pp. 339, 379, and 380.

expression is a further approximation and may be preferred to the exponential given above, $T = 10d^2 + (14d^2 + 3)100t$, or, as a further simplification, $T = 14d^2(1 + 100t)$ is given.

The tests for thrust on cast iron show a lack of consistency in spite of the fact that every care was taken. The thrust values for each drill size were plotted over the feed, and are represented graphically as straight lines which do not pass through the origin. A general expression for thrust in cast

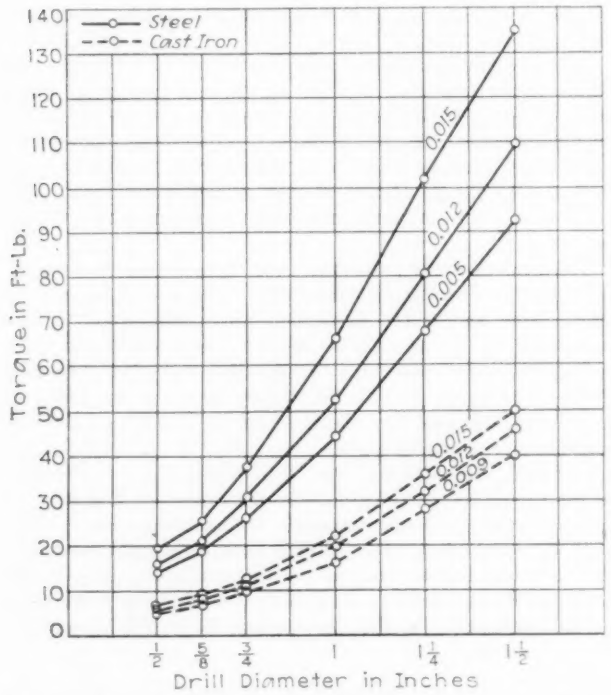


FIG. 20 VARIABLE DIAMETER TESTS SHOWING TORQUE FOR STEEL BAR IIIIII (0.15 PER CENT C) AND CAST-IRON BAR 8A (20 PER CENT CHARCOAL PIG)—FEEDS AT 0.009, 0.012, AND 0.015 INCH PER REVOLUTION—SPEED CONSTANT AT 230 R.P.M.

iron was developed, as follows: $Th = (d - 0.4)325 + (24d + 65)1000t$, in which Th = Thrust, d = drill diameter in inches, and t = feed in inches. This is more simply and approximately expressed by $Th = 240d + (24d + 65)1000t$, and for some purposes it may be good enough to take $Th = 200d + 10{,}000t$, which is roughly correct. The general expression for thrust is simplified to $P = 52{,}900\, t^{0.92 - 0.087d}$, which agrees with $P = 35{,}500\, d^{0.7} t^{0.75}$, as the latter is likely to prove most serviceable to the practitioner.

Similar equations are developed by Smith and Poliakoff for medium-hard steel, as follows: The general law for various drill diameters and feeds is $T = 2350\, d^{1.28} t^{1/5} d^{-0.64}$, T = torque in foot-pounds, d = drill diameter in inches, and t = the feed in inches per revolution. The general straight-line law is $T = 18d^2 + 100t(27d^2 + 20)$ but the approximate general law is $T = 1640\, d^{1.8} t^{0.7}$.

For thrust in medium hard steel the approximate general law is $P = 33{,}500\, d^{0.7} t^{0.6}$, in which P is the thrust in pounds.

Smith and Poliakoff conclude (Part II) as to the influence of feed on torque and thrust as follows:

"The net horsepower per cubic inch of metal removed is inversely proportional to $d^{0.2} t^{0.3}$ and independent of the revolutions. Thus the net horsepower per cubic inch of metal =

$$\frac{4 \times 2\pi N c d^{1.8} t^{0.7}}{33{,}000\, \pi d^2 t N} = \frac{k}{d^{0.2} t^{0.3}}$$ where c and k are constants.

"If the diameter of the drill remains constant and feeds of $^1/_{400}$ in., $^1/_{100}$ in., and $^1/_{25}$ in. are taken, the corresponding horsepowers will be in the order of 1, 0.66, and 0.435 which is in the order of the cutting pressures given on pages 343 and 345. If t remains constant and values of $d = ^1/_2$ in., 2 in., and 4 in. are taken, then the horsepower for each successive drill will be in the order of 1, 0.76, and 0.66 in."

"The end thrust when operating on cast iron or steel does not increase in proportion to the feed for a given diameter of drill or in proportion to the diameter for a given feed."

Both the torque and thrust curves for cast iron and medium-hard steel are therefore straight or slightly concave downward which does not agree in all instances with the authors.

The torque curve for the $^5/_8$-in. diameter drill cutting at a speed of 420 r.p.m. and various feeds from 0.004 to 0.020 in., as given by Bird and Fairfield[10] is concave downward, but the thrust curve appears to be excessively concave upward.

The tests on cast iron by H. M. Norris[11] show that for drills from $^1/_2$ in. to $1^1/_2$ in. in diameter when operating at feeds between 0.015 and 0.035 in. per revolution, the gross horsepower

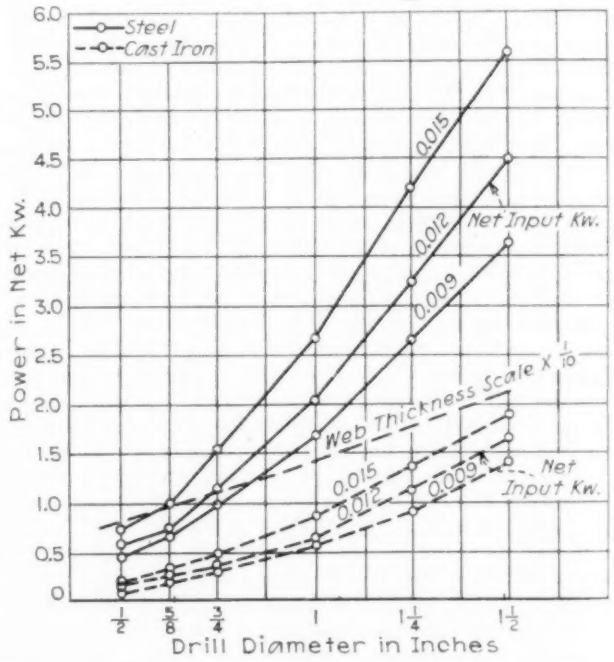


FIG. 21 VARIABLE DIAMETER TESTS SHOWING NET INPUT KILOWATTS FOR STEEL BAR IIIIII (0.15 PER CENT C) AND CAST-IRON BAR 8A (20 PER CENT CHARCOAL PIG)—FEED CONSTANT AT 0.009, 0.012, AND 0.015 INCH PER REVOLUTION—SPEED CONSTANT AT 230 R.P.M.

input varies practically as a straight line, although it is slightly concave upward for the lower values of feed. The horsepower per cubic inch of metal removed per minute is highest for the low feeds, and reduces gradually as the feed is increased, giving curves almost horizontal for the $1^1/_2$-in. diameter drill, but distinctly concave upward, and higher for the lower feed values for the $^1/_2$-in. diameter drills.

VARIABLE DIAMETER TESTS

The results of several tests to show the influence of the diameter on the torque for feeds of 0.009, 0.012, and 0.015 in. per revolution for all drill sizes from $^1/_2$ in. to $1^1/_2$ in. in diameter

[10] Ref. 3 of Bibliography.
[11] Ref. 2 of Bibliography, p. 74.

TABLE 8 DRILLING DATA SUMMARIZED FROM SPECIAL TESTS—VARIABLE SPEEDS AND FEEDS

		Material																			
		Cast-iron bar No. 20 (4-8-28)					Cast-iron bar No. 25 (char.)					Materials Steel bar No. IIIIII					Steel bar No. 6—S.A.E. 6150				
Drill size, in.	Feed in in. per rev.	Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Net input, hp.	Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Net input hp.	Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Net input, hp.	Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Net. input, hp.
		75.65	4.5	441.6	0.0648	0.110											75.5	20.0	776.25	0.2879	0.388
		152.2	6.3	400	0.1825	0.134											153.8	19.7	900	0.567	0.777
		234.4	6.3	450	0.2813	0.388											232.8	18.0	900	0.7985	0.897
1/2	0.012	297.4	6.0	457.5	0.3399	0.549											294.6	16.6	800	0.932	1.18
		358.3	6.3	500.0	0.430	0.643											358.3	17.6	817.5	1.201	1.31
		439.0	6.3	485.0	0.527	0.670											436.0	17.3	907.5	1.439	1.80
		75.5	23.0	900	0.3308	0.429											74.95	63.0	1767	0.899	1.09
		153.8	25.0	835	0.732	0.911											152.2	58.0	1783.33	1.682	1.93
1	0.012	232.8	25.0	900	1.108	1.31											228.9	58.0	1683.3	2.530	3.06
		297.4	24.7	875	1.399	1.68											292.6	59.0	1800	3.289	4.12
		356.0	24.5	912.5	1.649	2.18											347.3	59.5	1937.5	3.931	5.02
		436.0	23.7	850	1.968	2.37											413.5	59.0	1875	4.65	6.32
							76.48	36.50	968	0.532	1.02	74.94	82.7	2151.25	1.18	1.58					
							158.3	36.5	943	1.10	1.27	153.9	79.5	2175	2.331	3.02					
1 1/4	0.012						234.8	36.0	993	1.61	1.86	226.6	82.1	2262	3.541	5.13					
							299.7	37.0	1016	2.114	2.42	284.1	83.38	2376.25	4.515	6.56					
							364.0	35.3	995	2.44	2.96	343.2	82.28	2375.5	5.37	7.63					
							438.8	35.6	1025	2.972	3.60										
	0.006						158.1	22.875	595	0.689	0.78	157.1	48.5	1400	1.451	1.70					
	0.009						158.2	29.1	782	0.877	1.00	156.6	62.5	2017.5	1.863	2.41					
1 1/2	0.012						157.6	35.125	890	1.052	1.23	154.9	76.375	2250	2.253	2.97					
	0.015						157.1	41.375	1110	1.239	1.44	154.2	92.625	2670	2.717	3.24					
	0.017						157.1	45.95	1262	1.374	1.67	153.2	102.05	2831.25	2.973	4.10					
	0.019						158.1	50.2	1212	1.514	1.74	150.6	117.13	3100	3.358	4.50					

are shown in Figs. 20 and 21. Again, the set of R drills were used. The tests were conducted on an open-hearth steel bar IIIIII (0.15 per cent carbon), and a cast-iron bar 8-A which was made up of 20 per cent charcoal pig, similar to bar 20 used in the variable-feed tests, and bar 18 in the commercial tests.

The values of the torque in foot-pounds for the steel and cast iron at the three different feeds are shown in Fig. 20. The values for each curve were determined at times several weeks apart, so that the web thickness of each drill may have varied slightly. For all feeds, on both steel and cast iron, smooth curves are obtained. The torque increases rapidly as the diameter of drills is increased.

The net input in kilowatts as determined by the wattmeter for the torque tests is shown in Fig. 21. These values correspond favorably with the values of the torque shown in Fig. 20.

TABLE 9 DRILLING DATA SUMMARIZED FROM VARIABLE FEED, AND DRILL SIZE TESTS

Various Feeds for Each Diameter—Speed Constant at 230 r.p.m.

		Material																			
		Steel bar No. 6 (S.A.E.) (6150)					Steel bar IIIIII (0.15 per cent C.)					Cast-iron bar No. 20 (20% charcoal 4-8-28)					Cast-iron bar No. 8-A (20% charcoal pig)				
Drill size, in.	Feed in in. per rev.	Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Input, hp.	Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Input, hp.	Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Input, hp.	Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Input, hp.
1/2	0.006	232.0	10.35	650	0.5497	0.576						232.8	6.0	360	0.2659	0.134					
	0.009	232.8	14.8	781.25	0.656	0.710	238.2	14.0	700	0.6388	0.603	234.4	6.2	500	0.2767	0.294	241.5	4.0	220	0.1851	0.1474
	0.012	232.8	16.5	950	0.731	0.857	238.2	15.0	925	0.6867	0.777	234.4	6.4	560	0.2848	0.361	238.2	5.0	300	0.2286	0.227
	0.015	232.8	19.7	1150	0.8732	1.06	229	19.4	800	0.852	1.00	234.4	7.7	612.5	0.3436	0.493	238.1	7.0	350	0.3120	0.254
	0.017	232.8	21.3	1300	0.9441	1.16						232.8	7.8	655	0.3457	0.493					
	0.019	234	23.7	1467.5	1.055	1.39						234.0	9.0	712.5	0.4016	0.469					
	0.021	232	24.0	1550	1.060	1.44						232.8	9.25	725	0.4090	0.640					
5/8	0.009						236.9	18.5	887.5	0.8377	0.912						239.5	7.0	333.3	0.3214	0.2546
	0.012						234.6	21.0	1100	0.9498	0.991						241.5	8.5	367.5	0.3925	0.362
	0.015						229.0	25.6	950	1.124	1.31						231.8	9.0	412.5	0.4006	0.402
3/4	0.009						239.3	26.5	900	1.255	1.31						234.6	10.0	400	0.4659	0.5092
	0.012						236.6	31.0	1100	1.4069	1.54						237.1	11.5	500	0.5211	0.441
	0.015						227.4	37.75	1175	1.644	2.04						231.6	13.0	562.5	0.5759	0.643
1	0.006	232.0	34.33	983.33	1.516	1.78						232	16.7	600	0.7376	0.817					
	0.009	230.9	47.166	1230	1.842	2.46	234.4	44.0	1075	1.9707	2.109	230.9	21.0	753	0.9236	1.12	238.2	16.0	730	0.7259	0.7772
	0.012	229.5	59.5	1550	2.246	3.06	233.3	52.6	1400	2.3338	2.447	232.8	24.5	850	1.086	1.19	238.2	19.5	827	0.8856	0.857
	0.015	227.3	74.5	1880	3.224	4.05	226	67.12	2050	2.905	3.61	232.0	28.3	1037	1.250	1.51	227.7	22.0	712.5	0.7611	1.13
	0.017	226.1	83.0	2125	3.375	4.35						232.0	31.12	1100	1.373	1.60					
	0.019	232.0	93.0	2357.5	4.008	4.96						232.0	33.38	1285	1.470	1.83					
	0.021	224.0	104.6	2565	4.461	5.7						232.0	35.0	1368	1.546	2.07					
1 1/4	0.009						232.5	67.9	1850	2.3338	3.52						235.9	28.0	790.0	1.2612	1.2194
	0.012						228.9	81.0	2200	3.5432	4.36						234.4	32.0	860	1.4331	1.50
	0.015						220.8	102.43	2212.5	4.324	5.65						226.5	36.0	887.5	1.557	1.81
1 1/2	0.009						230.3	92.5	1925	4.2207	4.85						235.9	40.0	900	1.8018	1.876
	0.012						223.9	109.8	2612.5	4.3075	6.01						234.4	46.0	1070	2.060	2.21
	0.015						218.0	136.05	2062.5	5.661	7.51						226.3	50.12	1075	2.1692	2.50

The values shown in Figs. 20 and 21 are not only functions of the outside diameter of the drills, but of the particular geometric shape and size of each drill considering such items as the web thickness, shape and helix of the flute, chisel-edge angle, etc. The slight variation in the web thickness will undoubtedly influence these values considerably. Better to visualize the values of the web thickness of the drills after they have been ground a number of times, as taken from Table 1, and to compare the values of drills of different sizes, they are shown graphically in Fig. 21. The ratio of the web thickness to the diameter for the 1/2-, 5/8-, 3/4-, 1-, 1 1/4-, and 1 1/2-in. drills is 0.166, 0.15, 0.143, 0.14, 0.139, and 0.142, respectivley, showing that the web thickness is greatest in proportion to the diameter for the smallest drills.

The values of the thrust for the different drills of Figs. 20 and 21 were rather widely spaced. The general trend, however, of these curves is to increase in direct proportion to the drill diameter.

A second set of tests were run to determine the influence of the variable diameter on steel bar 6, S.A.E. 6150, and cast-iron bar 20 (20 per cent charcoal pig, dated 4–8–28) at a constant speed of 230 r.p.m. and a feed of 0.015 in. per revolution. These values are shown plotted in Fig. 22. The thrust curve for steel is practically straight up to the 1 1/4-in. diameter drill. The value for the 1 1/2-in. diameter drill is obviously low. The thrust curve for cast iron while slightly variable is also practically straight. Both thrust curves if continued to the left would pass through the origin.

The torque curves for both steel and cast iron are concave upward, and would obviously pass through the origin if continued to the left. The net input in kilowatts is also shown for cast iron and steel.

In order to determine more carefully the influence of the diameter on the torque and thrust the three torque curves of Fig. 20 for steel bar IIIIII (0.15 per cent carbon), and the torque curve of Fig. 22 for steel bar 6, were plotted on log-log paper. Four straight lines were obtained, the slopes n of which were as follows:

Bar 6 (S.A.E. 6150) at a feed of 0.015 in..... $n = 1.79$
Bar IIIIII (0.15 per cent carbon) feed 0.015 in..... $n = 1.93$
Bar IIIIII (0.15 per cent carbon) feed 0.012 in..... $n = 1.81$
Bar IIIIII (0.15 per cent carbon) feed 0.009 in..... $n = 1.805$

Similarly the three torque curves of Fig. 20 for cast-iron bar 8 A, and the torque curve of Fig. 22 for cast-iron bar 20 were plotted on log-log paper and the following values obtained:

Bar 8 A at a feed of 0.015 in..... $n = 1.97$
Bar 8 A at a feed of 0.012 in..... $n = 1.98$
Bar 8 A at a feed of 0.009 in..... $n = 2.0$
Bar 20 at a feed of 0.015 in..... $n = 1.97$

It may be that the exponents of the drill diameter d are different for steel for different rates of feed, but the fact that they are so close for the range in feeds given for bar IIIIII may indicate that 1.8 is a good average value. It is interesting to note that n for bar 6 at 0.015-in. feed conforms to the value of n for bar IIIIII at 0.009 in. and 0.012-in. feed, but that n for bar IIIIII for 0.015-in. feed is high at 1.93. This latter value was practically thrown out from the consideration. The values for cast iron are also very close for the different feeds and bars which indicates that 1.98, or an even 2, would serve well as an average value as an exponent for the drill diameter. The torque then for any material at any feed and speed may be expressed as: $T = C f^{0.8} d^2$, for cast iron, and $T = C f^{0.78} d^{1.8}$, for steel in which T is the torque in foot-pounds, d is the drill diameter in inches, f is the feed in inches, C is the function of the material to be determined by some means not now known to the author, unless some actual cutting tests have been performed on the particular material, from which C can be found. The nature of this constant is similar to the "hardness class" used by Taylor[12] and Barth, and it is the factor which determines the location of the materials in Fig. 5 or Table 11. Knowing the torque for a given drill diameter, feed, and speed in a certain metal, the torque at the same feed and speed (or any other speed) but for a different drill diameter may be determined as follows: $\frac{T_1}{T_2} = \frac{d_1^n}{d_2^n}$, in which T_1 and d_1 are the known torque and drill diameter and T_2 is the desired torque for the new diameter d_2; n is 2.0 for cast iron and 1.8 for steel.

The values of the thrust for steel bar IIIIII and cast-iron

[12] Ref. "On the Art of Cutting Metals," Trans. A.S.M.E., vol. 28, 1907.

TABLE 10 DRILLING DATA SUMMARIZED FOR SPECIAL TESTS

Constant Speed and Feed for Each Diameter

Drill size, in.	Feed in in. per rev.	Material: Steel bar No. 6 (S.A.E. 6150) Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Net input Kw.	Hp.	Material: Cast-iron bar No. 20 (4–8–28) Act., r.p.m.	Torque, ft-lb.	Thrust, lb.	Output, hp.	Net input Kw.	Hp.
1/2	0.015	234.4	20.2	1052.5	0.9015	0.84	1.12	232.8	6.1	500	0.2703	0.37	0.49
5/8	0.015	234.0	30.0	1300	1.336	1.12	1.50	232.0	11.2	652.2	0.4947	0.478	0.64
3/4	0.015	232.0	39.0	1565	1.722	1.57	2.00	232.0	15.5	733.33	0.6846	0.70	0.93
1	0.015	237.3	69.0	2100	3.117	2.75	3.68	232.0	29.0	1131.25	1.281	1.27	1.70
1 1/4	0.015	223.4	105.5	2737.5	4.490	4.64	6.21	232.0	41.0	1206.25	1.811	1.52	2.03
1 1/2	0.015	215.2	141.0	2791.6	6.777	5.77	7.73	228.9	59.5	1512.5	2.593	1.82	2.43

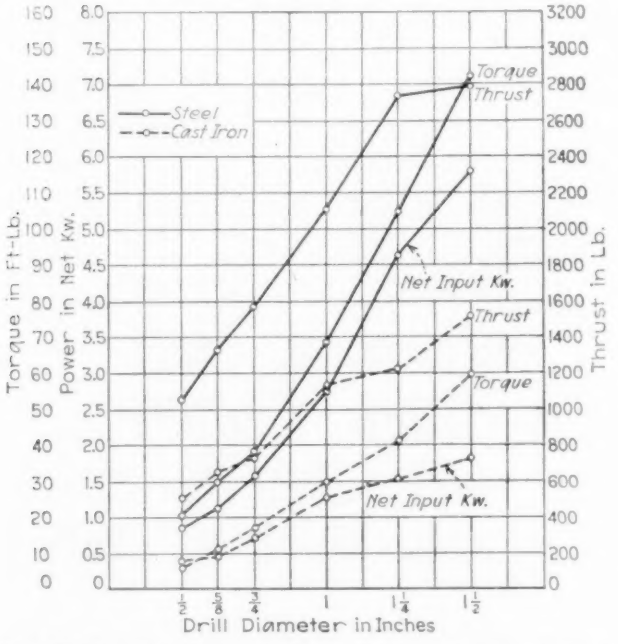


FIG. 22 VARIABLE DIAMETER TESTS SHOWING TORQUE, THRUST, AND NET INPUT KILOWATTS FOR STEEL BAR 6 (S.A.E. 6150) AND CAST-IRON BAR 20 (20 PER CENT CHARCOAL, 4–8–28) AT CONSTANT SPEED OF 230 R.P.M. AND CONSTANT FEED OF 0.015 INCH PER REVOLUTION

TABLE 11 MATERIALS GROUPED ACCORDING TO THE CHEMICAL COMPOSITION IN ORDER OF INCREASING TORQUE ON THE ONE-INCH DRILL

Bar No.	Carbon	Cr-Ni	Ni	Cr-Ni	Cr-Moly.	Cr-Va	Si-Mn
5		3135					
3			2320				
4		3120					
8		3140					
15					Cr-Moly[1]		
2	1045						
1	1020						
16					Cr-Moly[2]		
7				3250			
9				2330			
14							9250
6						6150	
10			2340				
13						6140	
12						6130	
19	1095						
11						6120	

[1] C. 0.33, Mo. 0.18, Cr. 0.66 (see Table 1).
[2] C. 0.28, Mo. 0.19, Cr. 0.65 (see Table 1).

bar 8 A at the three different feeds of 0.015, 0.012, and 0.009 in., the torque values for which were reported in Fig. 20, were also plotted on the log-log paper. The following values for n were obtained:

Bar IIIIII at a feed of 0.015 in..... $n = 1.1$
Bar IIIIII at a feed of 0.012 in..... $n = 0.955$
Bar IIIIII at a feed of 0.009 in..... $n = 1.09$
Bar 8-A cast iron at a feed of 0.012 in..... $n = 1.04$

Also the thrust values for steel bar 6 and cast-iron bar 20 as

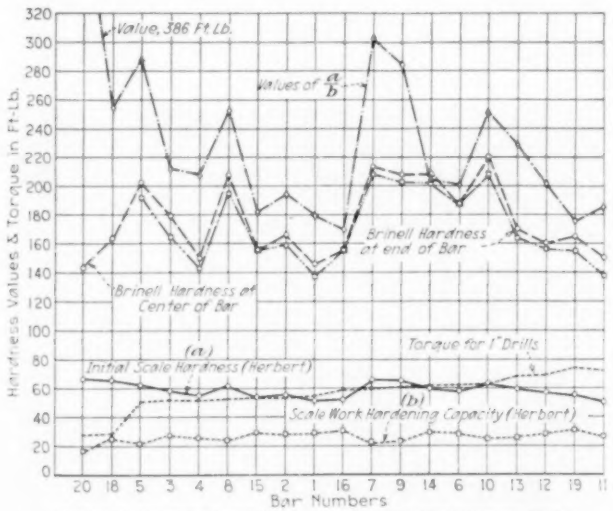


FIG. 23 CORRELATION OF DRILL TORQUE, BRINELL, AND HERBERT SCALE HARDNESS

reported in Fig. 22, were plotted on log-log paper, and the value of n was found to be as follows:

Bar 6 (S.A.E. 6150) at a feed of 0.015 in..... $n = 1$
Cast-iron bar 20 (4–8–28) at a feed of 0.015 in..... $n = 1$

It is concluded from the above values that the thrust varies almost exactly in direct proportion to the diameter of the drill. The values for thrust may be expressed then, as follows:

$$Th = C f^{0.8} d, \text{ for cast iron, and}$$
$$Th = C f^{0.8} d, \text{ for steel.}$$

The constant or "hardness class" C, will vary with the individual metal tested.

VARIABLE DIAMETER TESTS—RESULTS OF OTHER EXPERIMENTERS

H. M. Norris[13] concludes that when the speeds and feeds remain constant the power required is approximately proportional to the diameter of the drill.

Smith and Poliakoff[14] conclude that the torque increases almost in proportion to the square of the diameter of the drill for a given feed. The thrust is assumed to be a linear function. Their curves, however, show that the thrust curves for various feeds for a particular diameter do not pass through the origin, so that the conclusion is obviously wrong. They further conclude that the net horsepower for a given feed and speed does not increase as fast as the diameter, but varies as $d^{0.5}$. They further conclude that the net horsepower when operating on soft

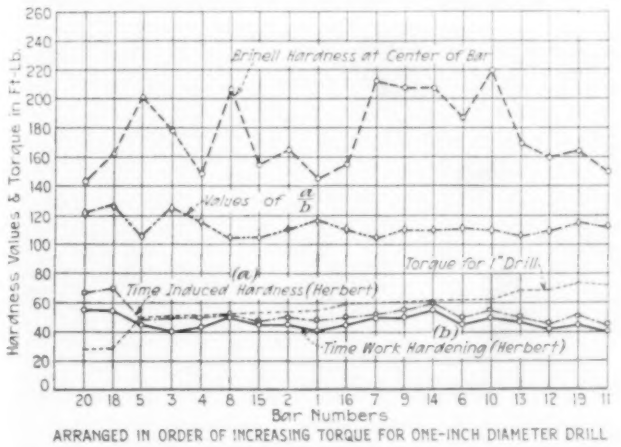


FIG. 24 CORRELATION OF DRILL TORQUE, BRINELL, AND HERBERT TIME HARDNESS

cast iron or medium steel varies as $t^{0.7}$ (feed), for a given drill and speed.

CORRELATION OF THE PHYSICAL PROPERTIES OF MATERIALS CUT WITH THE DRILL TORQUE

The values of the torque for the commercial speeds and feeds given in Table 5 for each drill diameter are plotted over the material numbers arranged in order of increasing torque on the 1-in. drill for its commercial cutting condition of 228 r.p.m. (60 ft. per min.), and a feed of 0.013 in. per revolution. These torque curves are satisfactorily smooth. A satisfactory mathematical equation might be written to represent the torque for a given drill and cutting condition, if some factor representing the machinability of the metals were known. In order to show part of the investigation on the correlation of physical properties with the drill torque, Figs. 23 and 24 were prepared.

In Fig. 23, the torque in foot-pounds for the 1-in. diameter drill, rotating at 228 r.p.m., and at a feed of 0.013 in. per revolution is shown plotted in light dashed lines over the bar numbers as abscissas arranged from left to right in order of increasing torque. The torque values for the two cast-iron bars 20 and 18 are about 27.7 and 27.9 foot-pounds respectively. The torque of 50.8 foot-pounds for steel bar 5, is the lowest of all the steels, while a torque of 74 foot-pounds for bar 19 is the highest. To the same scale as ordinates are also plotted in this figure the Brinell hardness numbers as taken at the end of the bar, at the beginning of the experiments, and at the center of the bar, for check purposes at the conclusion of the experiments, after

[13] Ref. 2 of Bibliography, p. 53, Conclusion 2.
[14] Ref. 4 of Bibliography, p. 341, Figs. 9 and 10, p. 379 (h).

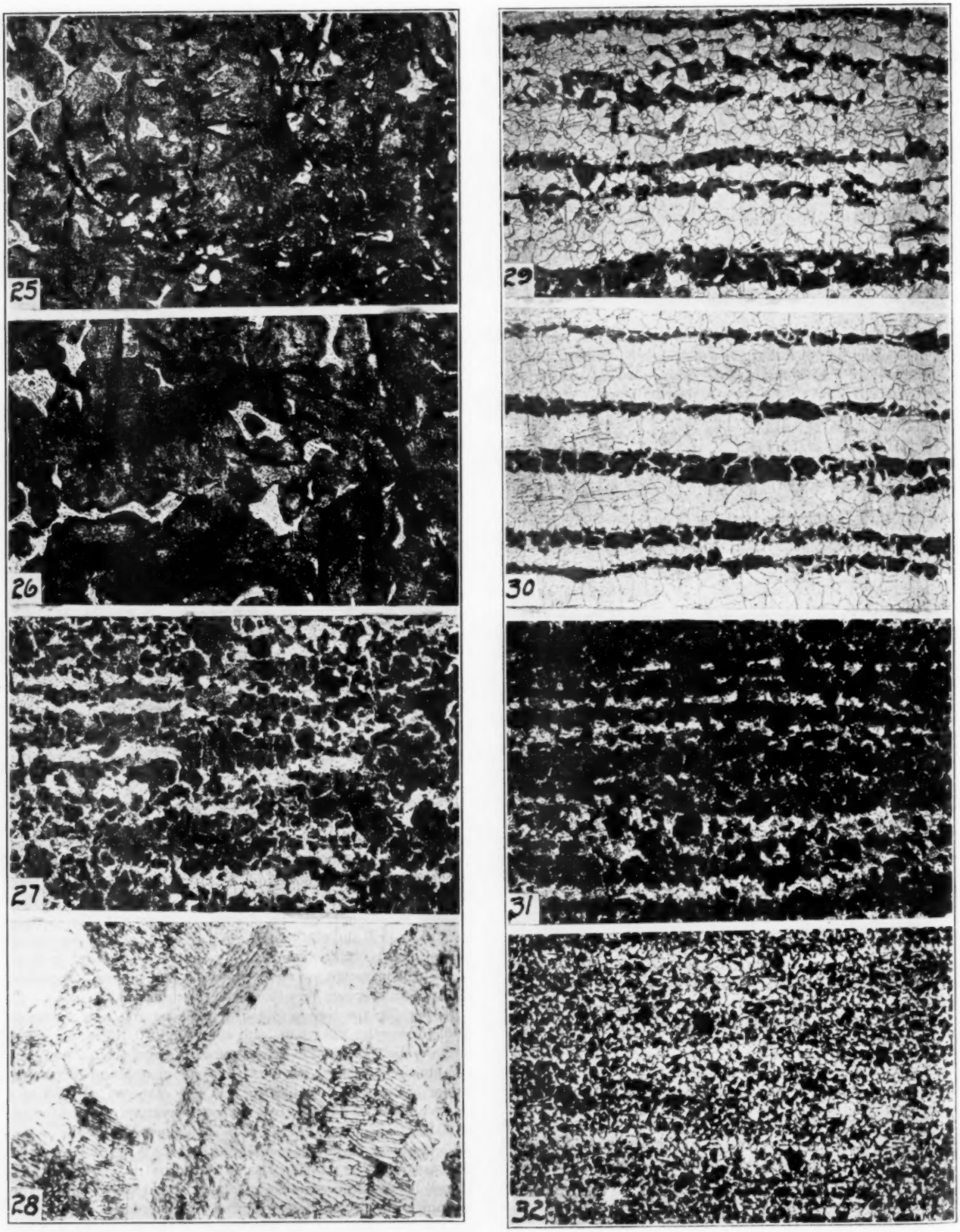


FIG. 25 BAR 20, CAST IRON; FIG. 26 BAR 18, CAST IRON; FIG. 27 BAR 5, S.A.E. 3135 STEEL, BANDED STRUCTURE, PEARLITIC, VERY SLIGHT SPHEROIDIZATION; FIG. 28 BAR 5, SAME AS FIG. 27, × 1000; FIG. 29 BAR 3, S.A.E. 2320 STEEL, BANDED STRUCTURE, PEARLITIC, SLIGHT SPHEROIDIZATION; FIG. 30 BAR 4, S.A.E. 3120 STEEL, BANDED STRUCTURE, PEARLITIC, VERY SLIGHT SPHEROIDIZATION; FIG. 31 BAR 8, S.A.E. 3140 STEEL, BANDED STRUCTURE, PEARLITIC; FIG. 32 BAR 15, CHROME MOLYBDENUM STEEL, BANDED STRUCTURE, PEARLITIC, WITH SLIGHT SPHEROIDIZATION

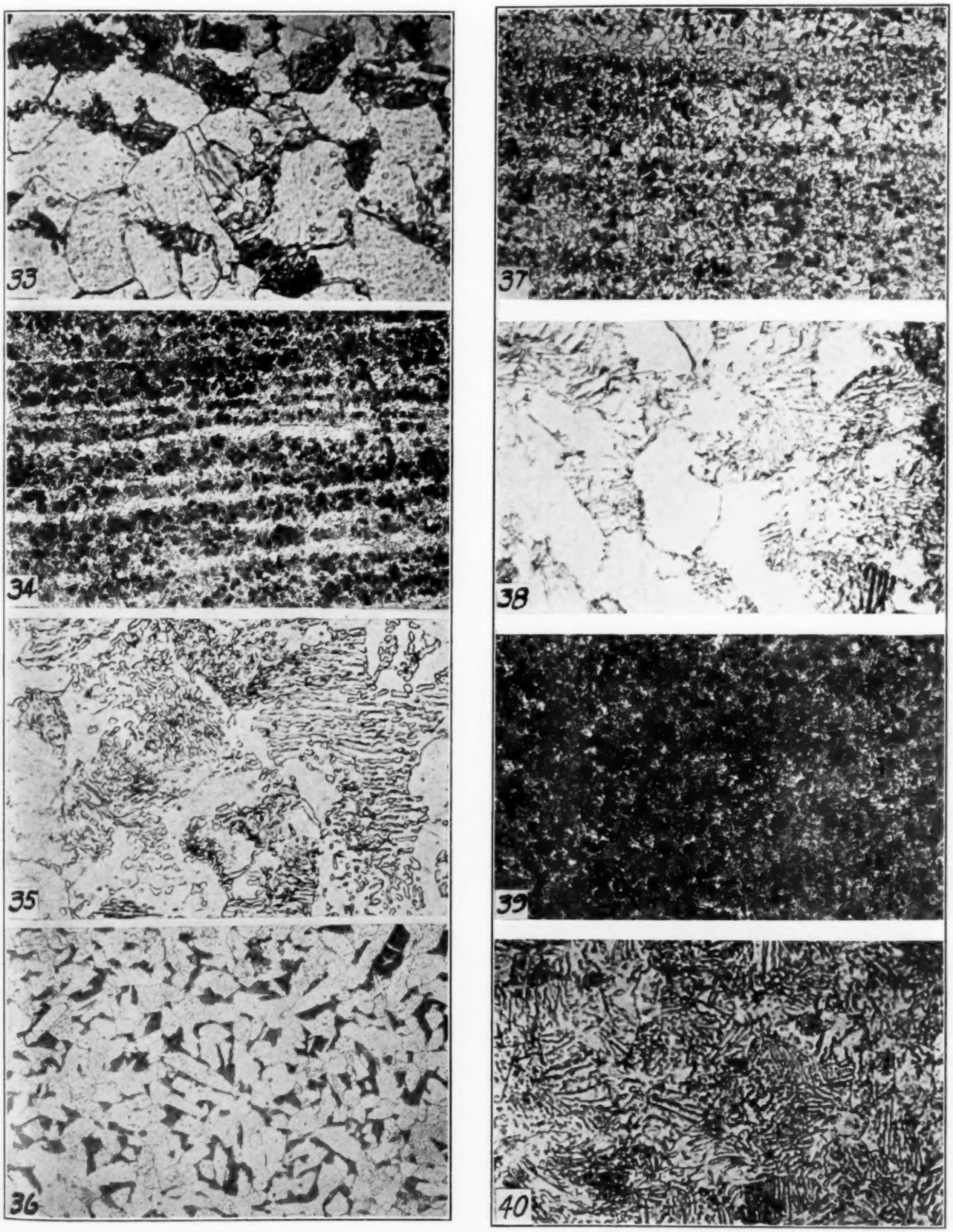


Fig. 33 Bar 15, Same as Fig. 32, × 1000; Fig. 34 Bar 2, S.A.E. 1045 Steel, Banded Structure, Pearlitic, Partially Spheroidized; Fig. 35 Same as Fig. 34, × 1000; Fig. 36 Bar 1, S.A.E. 1020 Steel, Pearlitic; Fig. 37 Bar 16, Chrome Molybdenum Steel, Banded Structure, Pearlitic, Partly Spheroidized; Fig. 38 Same as Fig. 37, × 1000; Fig. 39 Bar 7, S.A.E. 3250 Steel, Partial Spheroidization; Fig. 40 Same as Fig. 39, × 1000

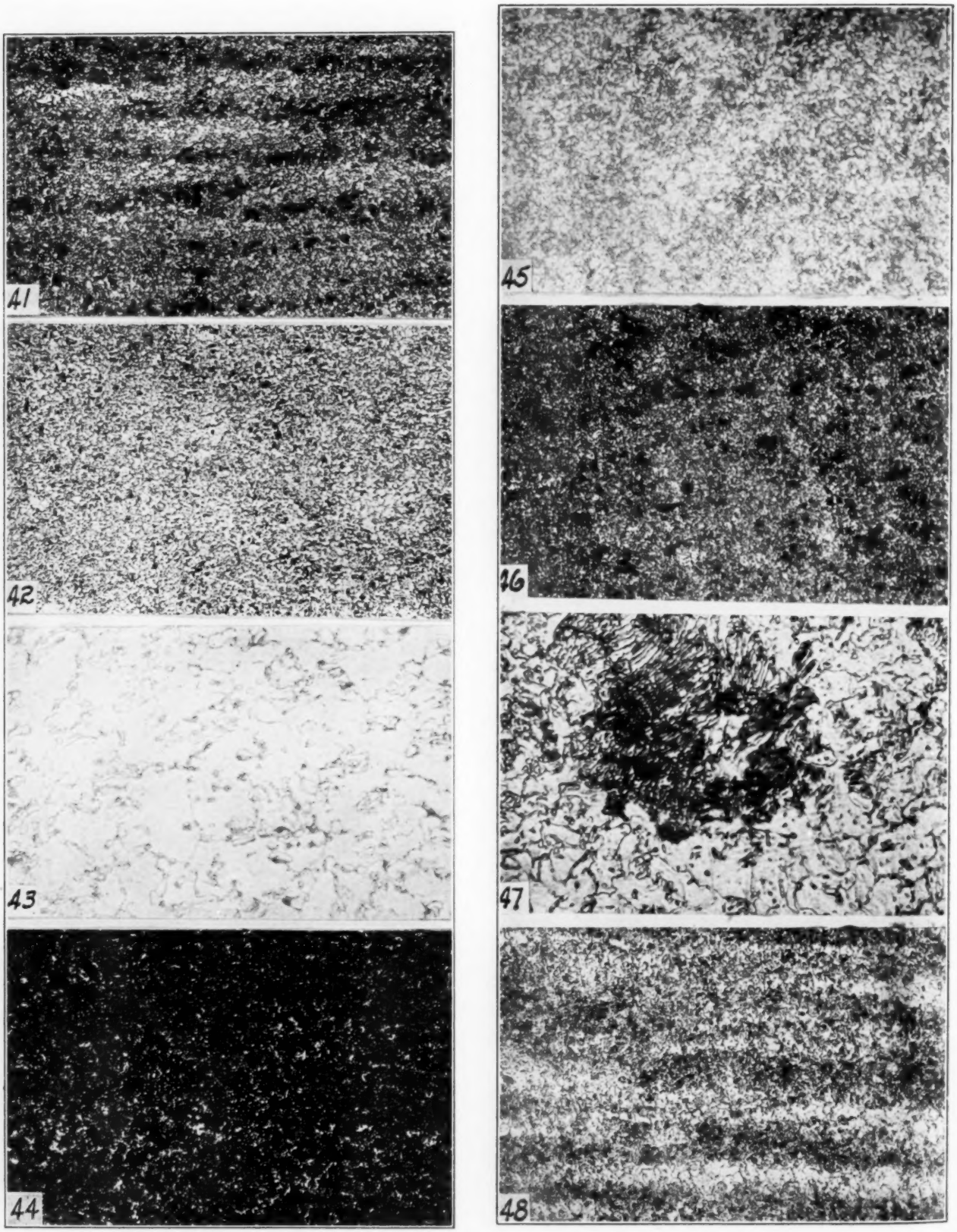
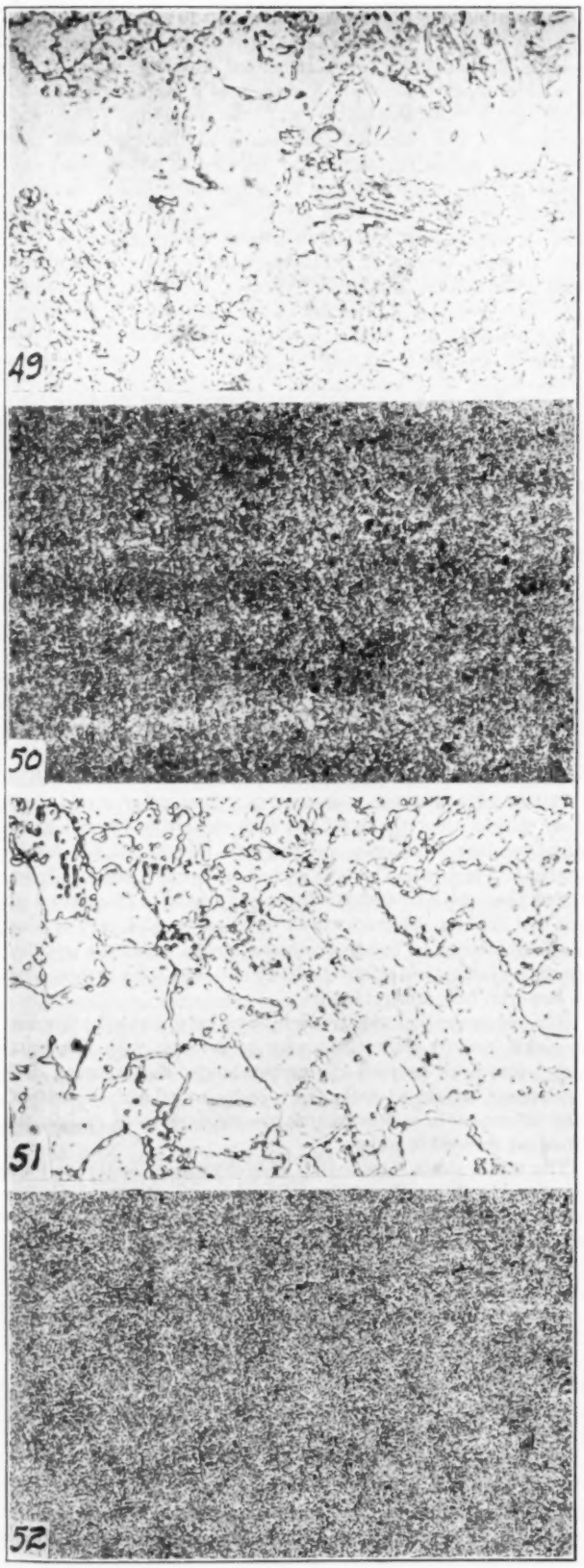


FIG. 41 BAR 9, S.A.E. 2330 STEEL, LARGELY SPHEROIDIZED, BUT NOT COMPLETELY. DIRECT AREAS OF LOW POWER CORRESPOND TO LAMINATED STRUCTURE OF HIGH POWER; FIG. 42 BAR 14, S.A.E. 9250 STEEL, SPHEROIDIZED; FIG. 43 SAME AS FIG. 42, × 1000; FIG. 44 BAR 6, S.A.E. 6150, SORBITIC; FIG. 45 SAME AS FIG. 44, × 1000; FIG. 46 BAR 10, S.A.E. 2340 STEEL, LARGELY SPHEROIDIZED, BUT NOT COMPLETELY, SIMILAR TO BAR 9; FIG. 47 SAME AS FIG. 46, × 1000; FIG. 48 BAR 13, S.A.E. 6140 STEEL, SPHEROIDIZED, BANDED STRUCTURE



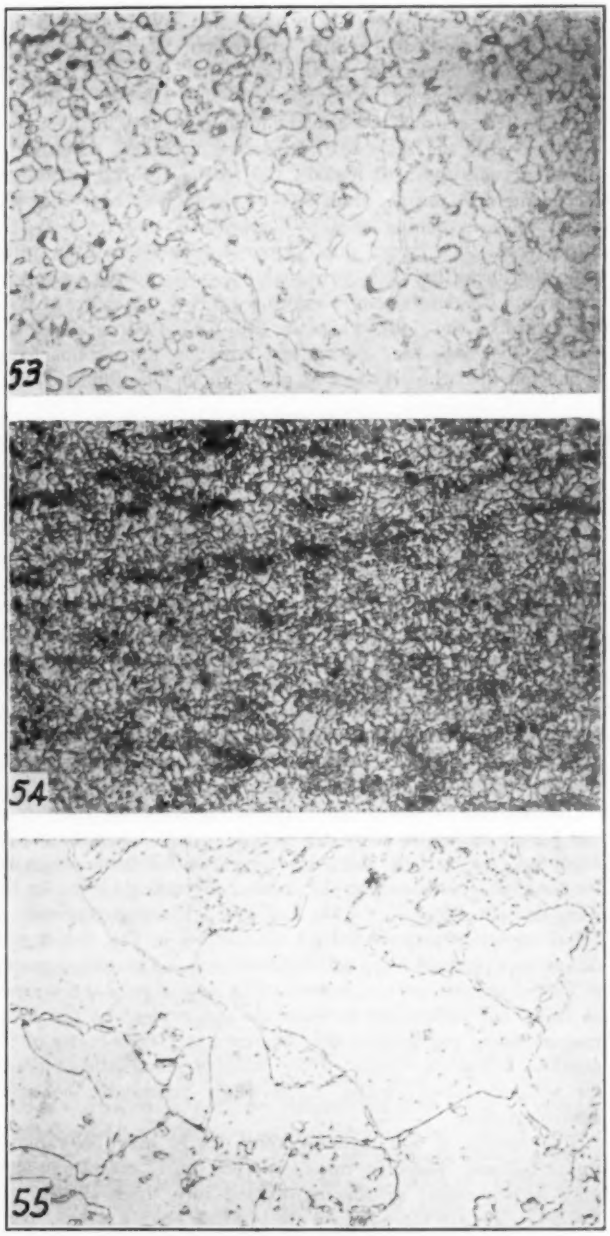


FIG. 49 SAME AS FIG. 48, × 1000

FIG. 50 BAR 12, S.A.E. 6130 STEEL, SPHEROIDIZED, BANDED STRUCTURE

FIG. 51 SAME AS FIG. 50, × 1000

FIG. 52 BAR 19, S.A.E. 1095 STEEL, SPHEROIDIZED

FIG. 53 SAME AS FIG. 52, × 1000

FIG. 54 BAR 11, S.A.E. 6120 STEEL, SPHEROIDIZED, BANDED STRUCTURE

FIG. 55 SAME AS FIG. 54, × 1000

milling off approximately 1/4 in. of metal. While these Brinell curves are practically parallel and equal, they show a wide divergence in curvature from the torque curve. The initial scale-hardness values determined by the Herbert pendulum hardness tester is also given in the form of a curve in this figure, together with the scale work-hardening capacity. Neither of these curves appear to explain the reason for the constantly increasing drill torque, from left to right. In order that the scale "work-hardening capacity" might be tied up with the initial scale "hardness," another curve, representing the initial scale "hardness" divided by the scale "work-hardening capacity," is shown. This latter curve shows a general tendency to slope downward to the right, while the drill-torque curve slopes upward. The scale-hardness values, however, appear not to be connected with the drill-torque, although they do follow closely, the Brinell numbers.

Fig. 24 shows over the bar numbers arranged as abscissas, in order of increasing torque for the 1-in. diameter drill, curves for the drill-torque for the 1-in. drill, the Brinell hardness numbers at the center of the bar, and three time-hardness curves, such as the time-work-hardening curve, the time-induced-hardness curve, and a curve representing the ratio of the time-induced-hardness to the time-work-hardness values, as determined by the Herbert pendulum hardness tester. Again, there appears to be no definite relation between these time-hardness curves and the torque curve. The author's experience with the Herbert pendulum hardness tester is limited to the tests presented here. The values for each bar are an average of at least two test values which were equal or nearly so. The instrument was repeatedly checked at intervals on plate glass throughout the tests.

In the hope of throwing additional light on the relation of the metals drilled to their drill-torque value, a metallographic study of the various samples was made. Photomicrographs for the metals are shown in the order of increasing torque for the 1-in. drill in Figs. 25 to 55, inclusive. Photomicrographs at 100 diameters are presented for all samples in the etched condition; a 4 per cent Nital solution was used. Photomicrographs at 1000 diameters are also presented for a number of the samples to bring out differences in structure not evident at the lower magnification, particularly the difference in the character of the pearlitic structure. Some of the samples show little tendency for spheroidization, while others show practically complete spheroidization.

The results of the metallographic study may be summed up, as follows: Based on microstructure the 17 samples of steel may be somewhat arbitrarily divided into three classes. In the first class are placed those steels which show a normal pearlitic structure, or one showing very slight spheroidization; in the second class are placed those steels which are partly spheroidized, that is, advanced beyond the beginning stage of spheroidization; and in the third class, are placed those steels which are completely, or very nearly completely, spheroidized. Those steels falling in class one, are bars 5, 3, 1, 4, 8, 15, and 2, in class two are bars 16, 7, 9, 6, and 10, and in class three, bars 13, 12, 19, 11, and 14. In Fig. 10 or 11, it is seen that the torque curve is practically horizontal for the first group, consisting of bars 5 to 1, inclusive, and higher but practically horizontal for the second group of 16 to 10 inclusive, and again, higher but practically constant for the third class of 13 to 11 inclusive. It should be noted, however, that bar 14 in Fig. 23 is out of order, as it appears with class two rather than with the metallographical class three. Bar 6 is also, in a way, an exception to the second metallographic class, in that it appears to be more of the sorbitic type of structure than that of the partially spheroidized pearlitic.

In, pointing out the above relationship it is not intended to attempt to justify the drawing of any general conclusions connecting machinability with structural characteristics. There are many other factors which enter into a correlation between drill torque (machinability) and the structure. The wide variation in the chemical composition of the specimens used necessarily makes impossible the drawing of any general conclusions. The results of this investigation indicate, however, that for the particular type of tests made and the materials used, a classification from a structural standpoint exists, with the exception of bar 10. This appears to be a classification from a horizontal standpoint, that is, the bars are grouped into three groups along the abscissa axis according to the degree of spheroidization. A direct connection with the torque curve of Fig. 23 is evident, although the greater the torque the greater is the degree of spheroidization. This is just the opposite of what might be expected if all bars were of the same chemical composition.

Considering the specimens from the standpoint of composition some interesting relationships appear. Table 11 shows the materials grouped according to chemical composition in order of increasing torque on the 1-in. drill as shown in Fig. 23.

It will be observed that arranging the specimens in order of increasing torque, a fairly close grouping according to chemical composition or type of steel is obtained. Two steels fail to conform to this grouping. These two exceptions are bar 19 of tool steel, and 10 of nickel steel, S.A.E. 2340. The grouping, however, is not consistent from the standpoint of increasing or decreasing carbon content. With some of the types of steel an increase in carbon content is accompanied by an increase in torque, with other types the reverse is true.

The carbon steels ranging from 0.20 to 0.95 carbon show a rather wide divergence in torque. Five other steels show lower torque than the 0.45 and 0.20 carbon steels which are found together, while only one, the 6120, shows as high a torque as the 0.95 carbon. The 0.45 carbon steel which shows a lower torque than the 0.20 carbon steel shows a banded structure with pearlitic slightly spheroidized as opposed to 0.20 carbon steel in which little or no banding appears, and in which the pearlitic shows no indication of spheroidization. The 0.95 carbon steel is, however, fully spheroidized.

The chrome-nickel steels which have been divided according to nickel content show the torque to increase with increasing nickel content. As with the carbon steels, the grouping does not appear consistent from the standpoint of carbon content. The differences in microstructure are not such as to explain the apparent reversal in order.

The nickel steels show a very wide divergence in torque for a correspondingly small difference in carbon content. A similar variation in carbon content for the 1 per cent and the 2 per cent nickel-chrome steels results in no appreciable change in torque. Here the difference in torque appears to be clearly related to microstructure. The nickel-chrome steels which are found together on the basis of torque have similar microstructures; the two nickel steels which are widely separated on the basis of torque have very different microstructures. Bar No. 3, the 2320 steel, shows a distinctly banded structure, coarse grained, and with pearlitic showing very little spheroidization. Bar No. 10, the 2340, shows a very slight banding, fine grained, and very largely spheroidized.

The chrome-molybdenum steels behave similarly to 0.20 and 0.45 carbon steels, the higher carbon showing slightly lower torque. The lower carbon molybdenum steel, however, shows a greater spheroidization of the pearlitic.

The chrome-vanadium group of steels are consistent with the 2 per cent nickel-chrome steels, and the chrome-molybdenum

steels in that increasing torque accompanies decreasing carbon content. Of these steels, three are practically 100 per cent spheroidized. The other, Bar No. 6, S.A.E. 6150, appears to be more of a sorbitic structure. The torque values for the three bars Nos. 13, 12, and 11, all of which had the same heat treatment, seem to indicate quite definitely, at least for this type of steel, that increasing carbon content decreases the torque when the steel is fully spheroidized. The silico-manganese steel which was fully spheroidized falls in the class showing higher torque value.

Table 11 would appear to indicate that the type of steel, the carbon content, and the microstructure are all very important factors in determining torque.

With reference to the photomicrograph showing the two cast irons, it will be evident that structural differences are not what would normally be expected from a commercial cast iron, and an iron made with addition of charcoal pig. In fact, the structures appear to be reversed, although neither one gives the characteristic appearance of an iron made with the addition of charcoal pig.

Conclusions

In arriving at the conclusions given it is to be understood that the drills used were supposed at all times to have a keen cutting edge and point, that is, they were in a sharp condition. A cutting fluid consisting of one part of soluble oil mixed with sixteen parts of water was used on all tests. Actual experimental results are given in every instance, rather than values determined by smoothing out curves. For this reason there will be some slight inconsistencies in the data presented.

1 The torque remains practically constant at speeds ranging from 74 to 441 r.p.m. for both cast iron and steel and for various drill diameters when operating under constant conditions of feed, lubrication, and material.

2 The thrust remains practically constant at speeds ranging from 74 to 441 r.p.m. for both cast iron and steel and for various drill diameters when operating under constant conditions of feed, lubrication, and material.

3 The net input which equals the gross minus the load on the machine running idly, increases directly with the speed for the conditions mentioned under 1 and 2.

4 The torque increases with the feed, but at a slower rate for a constant drill diameter and speed. For two cast irons, one carbon, and one alloy steel for various drill diameters from $^1/_2$ to $1^1/_2$ in. and for different speeds, the average conditions are represented by the following:

T = a function of $f^{0.6}$, for cast iron, and
T = a function of $f^{0.78}$, for steel.

5 The thrust increases with the feed, but at a slower rate when drilling cast iron and steel. For the conditions mentioned in 4, the following formulas represent average values:

Th = a function of $f^{0.6}$, for cast iron
Th = a function of $f^{0.6}$, for a carbon and an alloy steel.

6 In drilling a straight-carbon and an alloy steel with drills varying from $^1/_2$ to $1^1/_2$ in. in diameter, at constant speeds of 153 and 230 r.p.m., the torque increases with the drill diameter, but at a greater rate for both cast iron and steel. Average conditions for two cast irons, a plain carbon, and an alloy steel are represented as follows:

T = a function of d^2, for cast iron
T = a function of $d^{1.8}$, for steel.

This may be expressed again, as follows:

$\frac{T_1}{T_2} = \frac{d_1^n}{d_2^n}$, in which T_1 and d_1 are the known torque and drill diameter and T_2 is the desired torque for the new diameter d_2. n is 2.0 for cast iron and 1.8 for steel.

7 For the conditions outlined under 6 the thrust is found to vary almost exactly in direct proportion to the diameter of the drill. The values for thrust may be expressed then, as follows:

Th = a function of d, for cast iron, and
Th = a function of d, for steel.

8 Combining the above relations of torque and thrust for cast iron and steel, general equations may be written as follows:

$T = C_1 f^{0.6} d^2$, for cast iron,
$Th = C_3 f^{0.6} d$, for cast iron,
$T = C_2 f^{0.78} d^{1.8}$, for steel, and
$Th = C_4 f^{0.6} d$, for steel, in which T is the torque in foot-pounds, Th is the thrust in pounds, d is the diameter of the drill in inches, f is the feed of the drill in inches per revolution, and C may be called a "hardness class" number, or "machinability factor," that is, a constant depending upon the material being drilled. At the present time the authors know of no way, except by actual drilling tests, to predetermine these constants for torque and thrust, for a particular metal.

9 The output horsepower at the drill point may be computed from the torque T and thrust Th, from the formula

$$\text{Hp. (computed output)} = \frac{2\pi TN}{33{,}000} + \frac{ThfN}{12 \times 33{,}000} = 0.0001904\ TN + 0.00000252\ ThfN = N\ (C_5 T + C_6\ Th\ f),$$

in which N is the r.p.m. of the drill, f is the feed in inches per revolution of the drill and C_5 and C_6 are constants. It is seen then that the output horsepower at the drill point as computed from the torque and thrust is directly proportional to N. While the value of the thrust in pounds is usually relatively large, the resultant horsepower is only $^1/_2$ to 2 per cent of the total computed. For general purposes, then, the output horsepower developed at the point of the drill may be assumed to be due only to the torque or

Hp. (computed output) = $0.0001904\ TN$ in which
$T = C_1 f^{0.6} d^2$, for cast iron, or
$T = C_2 f^{0.78} d^{1.8}$ for steel.

10 The results of the metallographic study may be summed up as follows: The seventeen samples of steel as a group are arbitrarily divided into three classes, the first class showing a normal pearlitic structure, or one showing a very slight spheroidization; the second class consisting of those steels which are partly spheroidized, that is, advanced beyond the beginning stage of spheroidization; and the third class, those very nearly completely spheroidized. A direct connection with the torque in drilling as shown in Fig. 23 is evident, although the greater the torque the greater is the degree of spheroidization. This is just the opposite of what might be expected if all bars were of the same chemical composition.

11 By grouping the materials according to chemical composition in order of increasing torque on the 1-in. drill as shown in Fig. 23, a fairly close grouping according to chemical composition, or type of steel, is obtained. This arrangement tends to indicate that the type of steel, the carbon content, and the microstructure are all important factors in determining the value of the torque in drilling.

12 No satisfactory correlation between the hardness values as determined by the Brinell, Rockwell, scleroscope, or the Herbert pendulum hardness tester, and the drilling torque for a given specimen, is evident.

Acknowledgments

The authors wish to express their appreciation to the Uni-

versity of Michigan whose equipment and laboratory space was used for these tests, also to those who have assisted in the investigation and preparation of the data as follows: George Butters, Giles Barr, Raymond Johnson, and others, who assisted in conducting the tests and tabulating the data; to Warner Vaughan who assisted in the various computations and in drawing the curves; to Professor Claire Upthegrove of the Department of Chemical Engineering who prepared the photomicrographic discussion, and to William Telfer who assisted in the hardness determinations of the various specimens.

Acknowledgment is also made to the Engineering Laboratory of the Ford Motor Company which furnished the Herbert pendulum tester for the determination of the scale and time-hardness values of the metals.

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MSP-52-3

The Present Status of Cemented Tungsten Carbide Tools and Dies

By ZAY JEFFRIES,[1] CLEVELAND, OHIO

I HAVE accepted the invitation to lead the discussion this evening as a representative of what might be called the cemented tungsten carbide industry in America. I am associated with one of the companies manufacturing and selling cemented tungsten carbide in America, namely, the Carboloy Company, Incorporated. There are, however, three other main channels of manufacture and distribution in the United States. These are Thomas Prosser & Son, who are representatives of Fried. Krupp, and they deal largely with imported cemented tungsten carbide material made by the Krupp company in Germany. Also the Firth-Sterling Steel Company manufactures and sells under the trade name "Diamondite" a similar material, and the Ludlum Steel Company deals in a similar material known as Straus Metal.

Before preparing the discussion this evening I communicated with the other representatives of the cemented tungsten carbide industry and obtained information from them as to their opinion of the present status of this industry in America, so that in a sense I have come before you to present a sort of composite picture for the whole industry. I shall make no distinction, nor do I intend to imply that there is any fundamental difference between one brand of cemented tungsten carbide and another. The examples of performance to be reported later represent all of the brands.

Cemented Tungsten Carbide—Its Origin

The base metal of cemented tungsten carbide is tungsten. The hard component is tungsten carbide. It was known at least toward the middle or last third of the last century that ferrotungsten containing large percentages of carbon was excessively hard. The material, however, was also very brittle. Moissan, about 1898, produced in the electric furnace from tungsten oxide and carbon, a material which he described as a carbide of tungsten and he reported that it was very hard. There were no common methods for determining hardness in those days except the scratch method, but the hardness was sufficient to attract Moissan's attention.

About 1904 Just and Hanamann in Budapest invented the squirted, or pressed, tungsten lamp filament. In the process of making the filament they produced, in one stage, tungsten containing a small amount of carbon. Such filaments were so brittle and fragile that it seemed doubtful whether they would be commercial. In fact, as little as one-tenth to twenty-five hundredths of one per cent carbon in such filaments rendered them not only brittle, hot and cold, but rendered them so fragile that a large percentage were broken merely by handling. The tungsten lamp-filament industry, therefore, has been engaged in a battle against carbon from about 1904 until the present time. Even now, at times, carbonaceous material gets into the lamp and a little tungsten carbide forms at the grain boundaries of the tungsten near the point where the filament is joined to the leading-in wire. Under such conditions the tungsten becomes so brittle and fragile that a slight jar of the lamp breaks the filament.

Also, in one of the processes of treating tungsten wire, the filament is heated to a temperature around 1200 deg. cent., usually in an atmosphere of hydrogen. It was early learned that if the atmosphere were changed to a hydrocarbon atmosphere, say, by introducing a little kerosene or alcohol or gas, within a few seconds the filament became so brittle and fragile that it could be broken to pieces in the fingers. This resulted, notwithstanding the fact that the filament before the treatment had a tensile strength of 600,000 lb. per sq. in., and was quite ductile. The percentage of carbon required to produce this bad effect in tungsten was so small at times that it was difficult to detect it by chemical analysis.

It seems rather remarkable because of the fragility of tungsten containing a little carbon or fused tungsten carbide that the material which we are to discuss this evening could contain to from 85 to 95 per cent of tungsten carbide and be sufficiently tough for cutting-tool purposes.

Method of Producing Cemented Tungsten Carbide

The creation of this material represents a new metallurgy. The old metallurgy, especially the tool metallurgy, was essentially one of fusion and either use of the tool in the cast condition, with or without heat treatment, or the use of the tool after forging plus heat treatment. The present cemented tungsten carbide is produced by first manufacturing a very fine powder of tungsten carbide. The fine powder is then mixed with metallic cobalt. The mixture is then ball-milled, and, as Dr. Hoyt has shown, the action causes the cobalt to be smeared over the surface of the minute microscopic particles of the carbide. The mixture, after ball-milling, is then pressed into any desired shape and size. It may be partially sintered then by heating to a low temperature, in which condition it can be handled without breaking, and can be easily shaped with a steel tool. It is not really machinable in the sense that the metal can be cut by an ordinary tool, but partially sintered powder can be removed with ease.

The final sintering is done in an electric furnace with a hydrogen atmosphere at a brilliant white heat. This is the true cementing operation, and cobalt is the cementing material. It is known that the cobalt takes up a little of the tungsten carbide in the process, but essentially the finished product consists of minute particles of tungsten carbide cemented together with cobalt, or with cobalt containing some tungsten and carbon.

This material was developed in Germany by the Osram Lamp Works, Berlin, and the two men who are given the major credit for the development are Schroter and Baumhauer.

The development was first made for wire-drawing dies. The dies were to be used for drawing tungsten and molybdenum at elevated temperatures. Dr. Hoyt, of the Research Laboratory of the General Electric Company in Schenectady, started development work several years ago along the lines originally suggested by Schroter and Baumhauer. He made additional contributions to the development, and others have contributed also. The cemented tungsten carbide of today therefore represents the work of a good many people, not only in Germany but in this country as well.

Properties of Cemented Tungsten Carbides

In density, cemented tungsten carbide ranges, say, between

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Address delivered at a meeting of the A.S.M.E. Machine Shop Practice Division, Cleveland, Ohio, October 1, 1929.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

14 and 15, sometimes lower, sometimes a little higher, so that it is relatively dense. Its hardness is difficult to appraise. It has a very high resistance to abrasion. Its resistance to indentation is relatively less than one might expect from its resistance to abrasion. The tungsten carbide itself has a hardness about com-

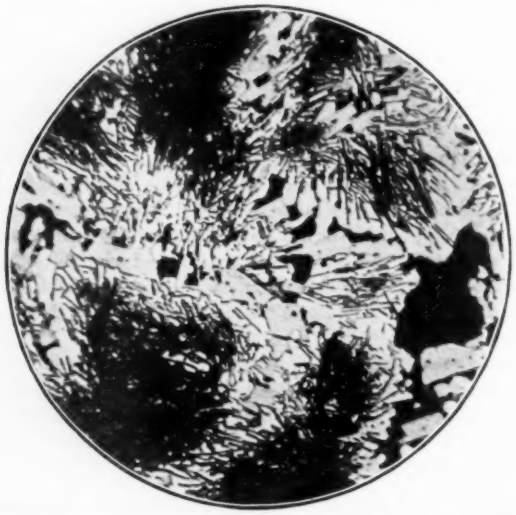


FIG. 1 PHOTOMICROGRAPH OF SECTION OF FUSED TUNGSTEN CARBIDES × 1000 (HOYT)

(Very hard but very brittle and quite fragile. Known for many years and unusable.)

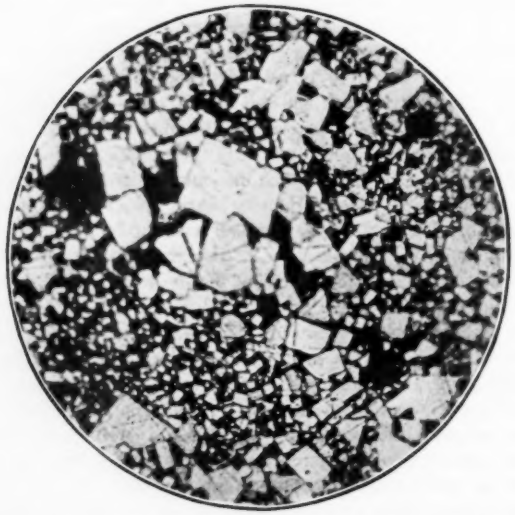


FIG. 2 ONE OF THE EARLIER CEMENTED TUNGSTEN CARBIDES × 1000 (HOYT)

[Showing carbide particles (light) surrounded by cobalt cement (dark).]

parable to sapphire or to corundum. The scratch hardness of the cemented tungsten carbide is equal to the hardness of the hardest constituent, hence is equal to the hardness of the tungsten carbide. The indentation is made easier by the presence of the cobalt, and hence the indentation hardness is relatively low as compared with the scratch hardness and as compared with the wear resistance of the material. The ordinary Rockwell hardness measurement on the C-scale will not suffice generally for the hardness measurement, but a smaller load is used, and a special hardness scale (the A-scale) is used for these materials. Other devices, such as the Vickers machine and the Monatron, as well as the Rockwell, can be used to evaluate the indentation hardness. There is no test for wear resistance equal to the service of tools in use, so that the appraisal of that factor is pretty much left to the user.

Whereas high-speed steel requires a special heat treatment to develop its hardness, cemented tungsten carbide is fully hard after cooling to room temperature from the high-temperature sintering operation. It cannot be softened by heat treatment alone. It can be reheated to a very high temperature and cooled either rapidly or slowly and it is still hard. Its red-hardness surpasses that of any other metallic substance used in the tool industry. No one knows just how hard it is at the high temperature, nor at what rate its hardness decreases at the higher temperatures. At any rate it appears that temperatures which are ordinarily reached even in relatively severe industrial operations are not high enough to materially affect the red-hardness of cemented tungsten carbide.

There are several ways of making cemented tungsten carbide, and there are two or three different grades available to the trade. These grades differ both in composition and in treatment during preparation. They differ in physical properties as well. One of the grades contains about 87 per cent of tungsten carbide and

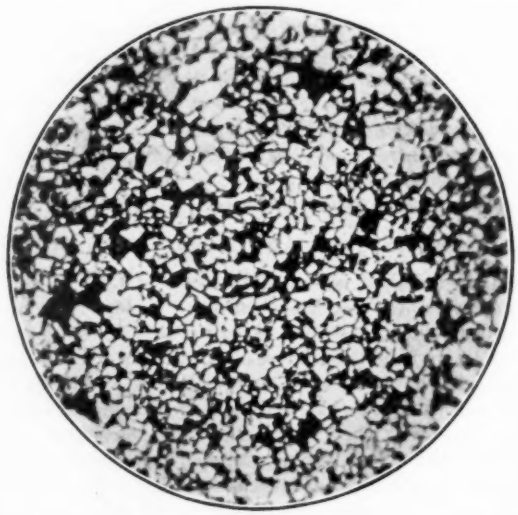


FIG. 3 ONE OF THE NEWER CEMENTED TUNGSTEN CARBIDES × 1000 (HOYT)

(Note that grain is finer and more uniform than in Fig. 2.)

13 per cent of cobalt. This grade is tough, having at times a calculated tensile strength, as determined by the transverse test, of 300,000 lb. per sq. in. It has a high compressive strength, one determination being 540,000 lb. per sq. in., the highest of any material which has been tested in our laboratory. Another grade contains about 6 per cent of cobalt. It is somewhat harder as measured by the indentation test and considerably harder as measured by the abrasion or wear test, and not so strong as measured by the transverse breaking test.

The industry is so new that the multiplication of grades has not reached the public. It is possible, however, by slight changes in composition and in methods of manufacture to produce quite a range of properties, and it seems practically certain that as time goes on industry itself will select from these possibilities what best suits its own purposes. Like every other new industry it has not begun to exhaust the possibilities of the present grades, but the time will come when additional grades will be available. We are hardly at the stage where we can measure small differences so that it is not surprising that relatively few grades would meet most of the requirements at hand. Also, those exploiting ce-

mented tungsten carbide are so busy with the grades they have that they lack the energy to consider additional grades at the present time.

Cost

Cemented tungsten carbide is offered to the trade at a relatively high price—in round numbers, $450 per pound. That, of course, is more than the material will cost in the future, and it is a price which none of us expect will be maintained in the industry. On the other hand, the industry is in the process of development, and development costs a great deal of money.

The first people to make investment in cemented tungsten carbide were those who carried on investigations and researches leading to its invention. The next group comprised the companies commercially exploiting the material. Following these came the machine-tool builders.

Having visited the National Machine Tool Builders' Exposition I can appreciate that the machine-tool builders have already put some hundreds of thousands of dollars into the development of machines which will have sufficient power for and be otherwise adapted to the use of cemented tungsten carbide, but before they did that, other groups put a considerable amount of money into researches on the nature of the material itself, on how to make it, and on how to use it. I cannot speak for the other groups, but the Carboloy Company is still spending money faster than it receives it.

In spite of the present price, in most of the analyses which we have we find that the user of the material employs it at a distinct saving to himself, so if any one should complain about the price it should not be he who buys a tool and uses it at a profit to himself, but those who are exploiting the material and the machine tool builders, both of whom have investments on which they have so far not realized any profit.

Utilization of Cemented Tungsten Carbide in Tools

Being a high-priced material, cemented tungsten carbide is utilized by the insertion of a tip in a shank of a cheaper material, usually some grade of steel. This has given rise to what is known as the tipping problem. Tipping has been taken care of in a number of ways. The art of tipping may not be all that is desired at the present time, and improvements can be expected in the future, but it has been found possible to put the cemented tungsten carbide tips on steel shanks by copper brazing in an atmosphere of hydrogen, with satisfactory results in most cases. There seems to be a preference for the welded tip for larger tools. The welding is attended by the hazard of cracking the cemented tungsten carbide itself, but when properly manipulated this hazard can be overcome. Both the welded tips and the brazed tips have been found satisfactory in service.

Not a sufficient number of people throughout the industry are conversant with the art of tipping to distribute cemented tungsten carbide to the industry haphazardly. On the other hand, some of the industrial companies have worked on this problem and are in a position to make their own tools. If a concern has only a little tipping to do, it is probably best to permit one of the companies specializing in putting on these tips to make the tools. All of the companies exploiting this material in America have organizations for doing the work, and these of course are at industry's service. At the present time, therefore, there are two ways of acquiring a tool: one is to design the tool and order it

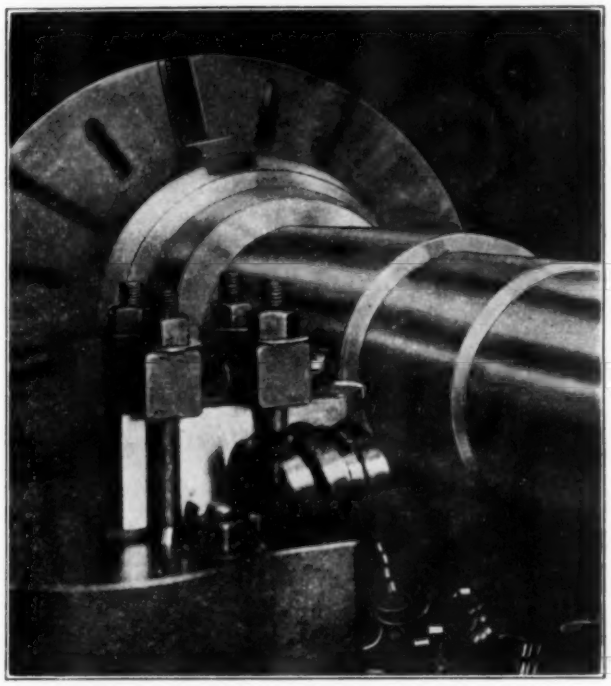


Fig. 4 Turning a Chrome-Nickel Steel Test Log With a Cemented Tungsten Carbide Tool

(Speed cutting, 70–75 ft. per min.; feed, 0.044 in.; cut, 3/8 in. A high-speed-steel tool lasts about 16 sec. on this test; cemented tungsten carbide is required to last 10 min., and may run for several hours.)



Fig. 5 Use of Cemented Tungsten Carbide Tools for Large Operations—Planing Section of Steel Flywheel, or Boring Mill, With Two Tools

tipped and ground, and the other is to buy the material and make the tools yourselves. There may be some advantage to the exploiters of this material in the latter method because companies

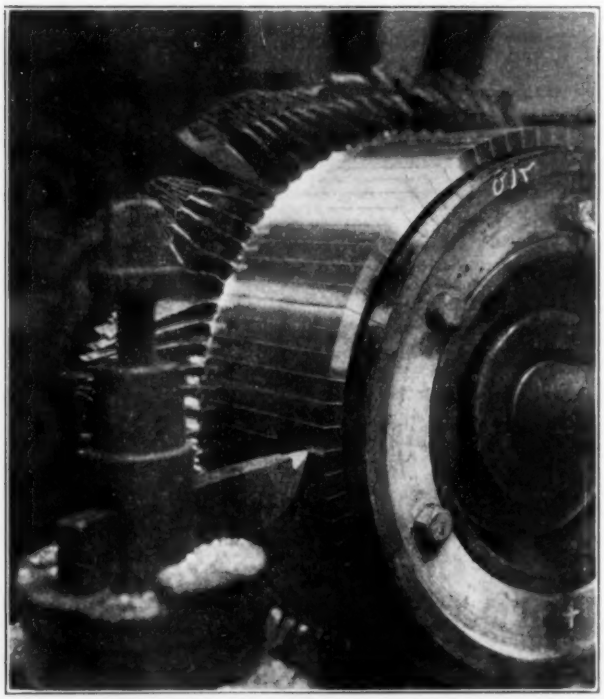


FIG. 6 TURNING A COMMUTATOR WITH A CEMENTED TUNGSTEN CARBIDE TOOL

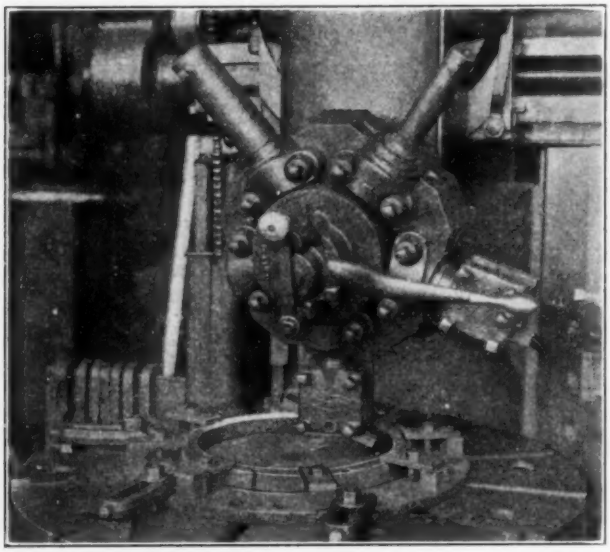


FIG. 7 TURNING A CARBON PACKING RING WITH A CEMENTED TUNGSTEN CARBIDE TOOL

putting on their own tips are satisfied with very much poorer jobs of tipping than when buying finished tools. If the cemented tungsten carbide cracks during the tipping or grinding operation in one's own plant he uses the tool anyway, and finds sometimes that it lasts as long as if the crack were not there; but if he orders a finished tool he rightfully demands that it shall be free from defects.

TOOL GRINDING

The next problem in connection with the manufacture of a tool is grinding, and without attempting to go into detail it may be said that there are several companies in the United States that sell wheels suitable for the grinding of these materials. The base material for these grinding wheels is in most cases, and perhaps

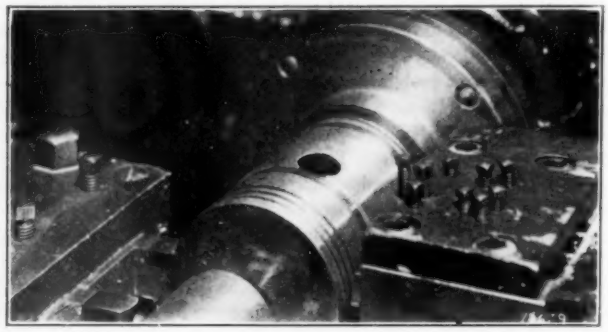


FIG. 8 MACHINING AN ALUMINUM-ALLOY AUTOMOBILE-ENGINE PISTON

(Metal is a high-silicon alloy, machinable only with the greatest difficulty with ordinary tools; about 10 pistons before dulling; with cemented tungsten carbide tools some of the operations will run 300 to 500 pistons between grinds, and with others, 2500.)

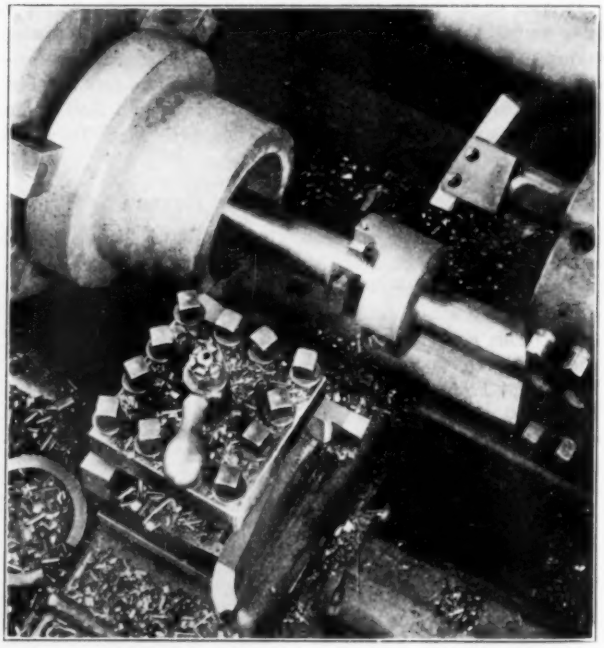


FIG. 9 ROUGH BORING AND FACING WITH CEMENTED TUNGSTEN CARBIDE TOOLS

all cases, silicon carbide, known as carborundum, or crystolon. Whereas six or eight months ago the matter of grinding these tools was a serious one, at the present time it may be said that that problem has at least passed the temporary crisis. There are certain precautions which the user will soon learn, but the information can be obtained from any of the companies exploiting this material and from the grinding-wheel companies.

USES OF CEMENTED TUNGSTEN CARBIDE

Now as to the uses of cemented tungsten carbide. The branch of the Society represented here tonight is principally interested in

machine-shop practice, or the use of tools in machining. The material—cemented tungsten carbide—has a much broader application. I shall mention a few cases to show some of the applications of this material, and so far as I know each case cited is a commercial one and not an exceptional performance.

There seems to be a tremendous field for its use in wire-drawing dies. I shall give two examples, one in which the competing material is the diamond die and the other is the chilled-iron die. In the first case the cemented tungsten carbide die drew 57,800,000 ft. of screen wire, 0.0108 in. in diameter, with a wear of 0.0007 in. in diameter. At this size the performance was approximately equivalent to that of a diamond die, but with more cuts possible in the case of cemented tungsten carbide. The overall improvement in cost on a performance basis over diamond was 6 to 1. The second example is the drawing of steel wire 0.105 in. in diameter. Over a 12-day period 264 chilled-iron dies were used in this line. Over the same period one cemented tungsten carbide die performed without going off size, or one cemented tungsten carbide die took the place of 264 chilled-iron dies. On the basis of die cost alone the cemented tungsten carbide was cheaper than the chilled iron in the ratio of 36.6 to 18. In addition, 20 per cent more wire was produced during the period

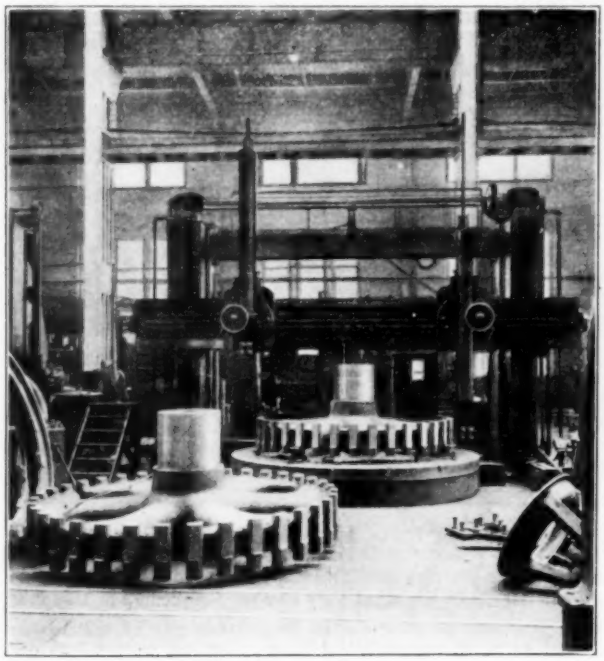


FIG. 10 COMMERCIAL USE OF CEMENTED TUNGSTEN CARBIDE TOOLS ON INTERMITTENT CUTS—TURNING LARGE CAST-IRON ROTOR SPIDER

by the one cemented tungsten carbide die than by the 264 chilled-iron dies. Cemented tungsten carbide dies are also being used for the hot drawing of tungsten and molybdenum, and more will perhaps be heard in the future about its use in the hot drawing of other materials.

The material is also usable in blanking dies, and in particular by the General Electric Company in punching transformer disks. It is found that the cemented tungsten carbide blanking die produces a material free from burrs. In blanking 200,000 disks the first one and the last appeared to be just alike.

ABILITY TO CUT HITHERTO UNMACHINABLE MATERIALS

Cemented tungsten carbide is used for cutting materials which no other metallic material has been able to cut. In that sense it is opening up a new field for machining. Machining is only one method of shaping articles, and has been used to a much greater extent in shaping metals than it has for everything else combined.

Cemented tungsten carbide can machine glass, porcelain, compounds used in the electrical industry such as Micalex, ivory, and materials of that sort. It machines various non-metallic

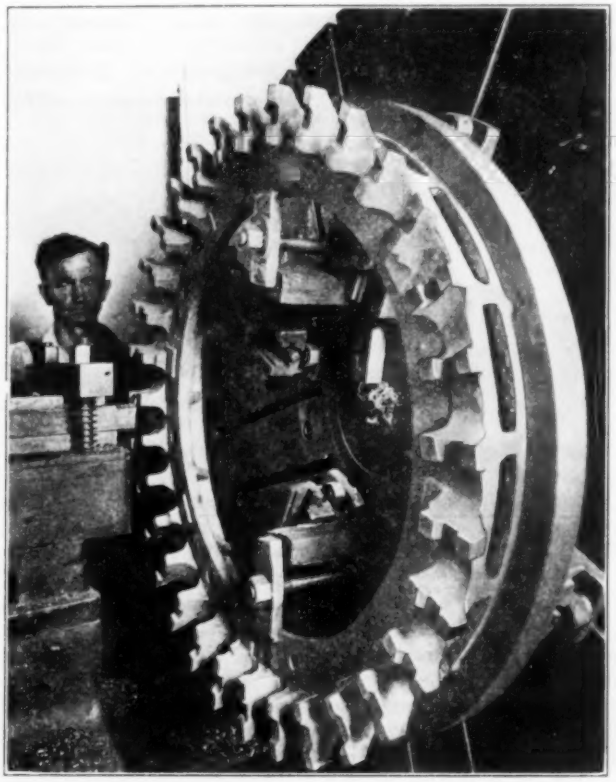


FIG. 11 ANOTHER EXAMPLE OF USE OF CEMENTED TUNGSTEN CARBIDE TOOLS ON INTERMITTENT CUTS

materials known as the fibrous materials which are abrasive, those containing mixtures of asbestos and other materials used in brake linings and floor boards, and it machines molded products of the bakelite type. In some instances it replaces diamond in those operations, but in other instances it makes possible the machining of parts which heretofore could not be shaped economically by machines with any known tool. Just where that will lead in the future, no one knows, but I think it should be a very interesting possibility as viewed from the standpoint of the Machine Shop Practice Division of The American Society of Mechanical Engineers.

The material is also used for cutting rock. It can be used to saw rock, replacing the old-time sawteeth of other materials with cemented tungsten carbide. It is also used in gages, knife edges, blast nozzles, etc.

It should be obvious that when a new tool material with the capabilities of cemented tungsten carbide is made available, existing machines may not be able to take full advantage of it. Nevertheless, the machines which have been made during the past five, ten, or even fifteen years have been adapted, in a way, to use this material, and whereas one would not expect a maximum performance from these machines, it is interesting to see what performance has been obtained.

Comparative Examples of Tool Replacement

In turning a laminated armature by the old tooling methods and tools the performance was one armature per grind. With cemented tungsten carbide 40 armatures were turned per grind. The speed was 700 ft. per min., hand feed, and the cut $^1/_{64}$ in.

For rough and finish turning commutators, the old record with the existing tools was 150 pieces per grind; with cemented tungsten carbide it was 30,000 pieces per grind.

Another example is a cut-off tool; the old performance was 100 cuts per grind; cemented tungsten carbide, however, made 15,000 cuts per grind.

In profiling 1020 S.A.E. steel at very high speed the old practice was 60 pieces between grinds; with cemented tungsten carbide it was 25,000 pieces.



Fig. 12 Heavy L-Shaped Tool for Intermittent Cuts
Tool, $1^1/_4$ in. deep; shank, 1 in. wide; L, $1^3/_4$ in. wide; inserted cemented tungsten carbide tip, $^3/_4$ in. × $1^1/_4$ in. × $^7/_{16}$ in. thick.)

Ivory has been turned at 6000 ft. per min., hand feed, with only a skin cut, with a result about the same as that obtained with a diamond tool.

In boring main-transmission-bearing holes $4^1/_2$ in. in diameter, in cast iron, 100 to 125 pieces per grind with the old tools was considered good, but 950 per grind were machined with cemented tungsten carbide.

In finishing boring of a bronze bushing with a tolerance of 0.0005 in., the old record with existing tools was 150 per grind, and with cemented tungsten carbide, 7000. There was, with the cemented tungsten carbide, only 5 per cent of the machine scrap that was obtained with the other tools. That is a very significant point, I think; namely, that in machining to close tolerances, the longer the life of the tool the less the machine scrap.

In reaming a malleable-iron differential carrier with a $3^3/_4$-in.-diameter hole, at 70 ft. per min. with a $^1/_{64}$-in. cut and hand feed, there were, with the old tools, one to two adjustments per day; with cemented tungsten carbide one tool had been running for eleven weeks without changing when this report was received.

With a 16-in.-diameter circular saw having inserted teeth, the increase in speed was from 900 r.p.m. to 1600. Cutting artificial floor-board material made of magnesia, asbestos, and wood shavings, the steel saw cut 80 ft. of board between grinds and cemented tungsten carbide, 1520; this represents a 78 per cent increase in speed, and an 1800 per cent increase in footage between grinds.

I could mention many more specific examples, but I think enough has already been written on the subject, and you have had enough experience of your own to know that in many instances, at least, the type of result mentioned earlier is now obtainable with the existing tools and tool equipment. There are some other features in connection with these results which I have not mentioned. In nearly every case, without change of labor, the production of the plant has been increased. It is seldom that the production is not increased 15 per cent, and in a number of cases it has actually been increased over 100 per cent. With machine tools especially adapted to take advantage of the properties of cemented tungsten carbide, much more spectacular results than those reported above have been made. Some such performances can be seen now at the Machine Tool Exposition.

The Commercial Situation

It may be said that cemented tungsten carbide received its initial publicity in the United States approximately one year ago. It is true that some of the tools from the Krupp works had been sold prior to that time. It is an interesting point here to note that fifteen months ago one tool was sold to a large manufacturer in the United States and that tool is still working, and in fifteen months it has replaced 2450 lb. of the type of tool material which was being used at the time this cemented tungsten carbide tool was introduced. But generally speaking, about one year ago the whole country became conscious that there was such a material as cemented tungsten carbide. Naturally the machine-tool builders had to make tests of their own to warrant their own expenditures in developing machines to better fit the properties of cemented tungsten carbide, and I think it is paying them

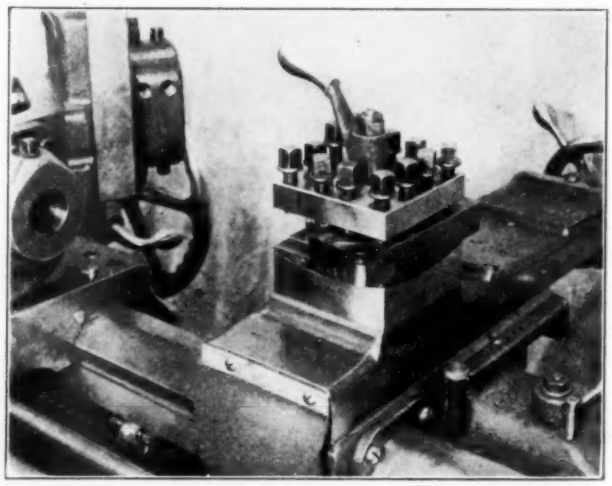


Fig. 13 Showing Rigid Mounting of Tool Illustrated in Fig. 12

a great tribute to see what they have accomplished in this short time.

With so much accomplished in one year can we not look confidently forward toward a still more rapid development?

Just a brief statement about the commercial situation. A year ago there was a clamor for tools, and for months the imported material and the material made in this country was not sufficient in quantity, or could not be made into tools rapidly enough to fill this demand. The first interest was naturally for trial purposes, and there was no great demand from any one source. The expense of trying to comply with such a demand, of course, was tremendous, and it also put quite a tax on the organizations. But all of them fought with the situation until about the middle of the past summer. Since then the delivery dates on most of the ordinary tools have been short. The same condition now obtains. There are, however, a number of tools desired by the industry which it has not been found practical or expedient to make at the present time, such as very large dies for drawing rod and tubing, but that demand will be taken care of in the not-distant future.

For the past three months the various companies have been in a position to supply ordinary tools faster than the industry has desired them. Within the last few weeks, however, the demand has increased to a point which is taxing the producing organizations.

The advent of high-speed steel was a great thing for not only the steel industry, but for all industry. It was a great thing for mankind. It has played a major role in our economic civilization, and it has perhaps done more than any other one development in the last twenty-five years to help make men economically independent, and to help make the expenditure of a given amount of human energy produce more of the necessities and luxuries of life. Its advent, however, did not reduce the amount of carbon-steel tools used. There are apparently today being made every year more carbon-steel tools than were made in the year 1905. I am not picking out 1905 as a depression year, but the year when high-speed steel began to have a real effect on production. In the same way we do not anticipate that cemented tungsten carbide, even though it be sold much more cheaply than it is today, will eliminate high-speed-steel or carbon-steel tools. I strongly suspect that in, say, 1935 there will be more high-speed steel made per year than in 1929. Furthermore, we do not regard this material as a cure-all for everything in the tool industry. Some applications have met with very indifferent success, and some attempted applications can be branded at the present time as absolute failures.

Future Possibilities

We do not know where this material will lead us, especially from the standpoint of tool substitutions. We are learning, and you are learning, and when we put all of our knowledge together we are going to find out what is economical and what is not. It seems to me, however, that we have gone far enough so that we can say definitely that cemented tungsten carbide is destined not only to have a definite place in the future of industry, but a most important place. That it will be used in large quantities and for a great variety of purposes in the future there can be no question. One of the results is going to be the enhancement of the high-speed-steel and stellite era toward greater economic benefits for mankind. It seems reasonable that the material offers the possibility of increasing, on the average, production in machine shops to the extent of 20 per cent, or will make possible the production in five days of what now takes six. If so, it must benefit all of the people, because machined goods will cost less. It will benefit the metal industries because more metal can be used, and more metal will be put into shavings and turnings than is done at the present time. Machining enters the field of competition in the shaping of metals with an improved tool, hence it is only natural that a larger percentage of the shaping of materials will be done by machining.

In closing, I should like to mention the important part played by the Machine Shop Practice Division of The American Society of Mechanical Engineers in connection with the commercial exploitation of cemented tungsten carbide. Last December, they formed a committee known as the Special Research Committee on the Cutting of Metals, and at the Rochester meeting they presented a report entitled, "The Present Status of Tungsten Carbide as a Cutting Material." That report not only very accurately reflected the status of the industry at that time, but it contains some very important and far-reaching suggestions for the activities of the Society and for the guidance of the machine-tool industry. Your Division has taken a leading part in the dissemination of knowledge on this subject, in the appraisal of possibilities, and has presented the information in an accurate and dignified manner. I wish to compliment it for the part that it has already played in connection with this industry, and I hope that it will continue to take as active an interest in the future as it has in the past.

Discussion

Roger D. Prosser.[2] Since the development of cemented tungsten carbide by the Krupp Works and its commercial introduction in the latter part of 1926, there have been produced by Krupp more than 500,000 Widia cutting tools and tips. Cemented tungsten carbide is now obviously long past the experimental stage so far as cutting tools are concerned. It is working successfully and is indispensable in many shops throughout the world.

The realization that better machine tools will be necessary to utilize fully the possibilities of tungsten carbide tools has been an incentive to machine-tool builders throughout the world, and new and better machines, especially designed to use the new tools, are appearing from day to day.

The remarkable increases in cutting speed, with corresponding increases in production, and the greater length of time between grinds, made possible by these new tools, are too well known to need further comment. However, the final result of the installation of a large number of these tools will doubtless be of interest. A number of shops are fully tooled up with Widia, and have increased their entire output over 100 per cent. This increase could only be attributed to Widia, as no new machine tools were purchased and no additional labor was employed. This remarkable result can better be visualized by considering that with a shop only half as large as before, with only half the number of machine tools and only half the number of workmen previously employed, they would still be able to produce the same output as before through the use of Widia tools.

In the introduction of any new material of this nature it is, however, inevitable that there will be some who will not at first secure the best results for various reasons. Most of the early troubles have now been overcome through efforts of the manufacturers in conducting extensive campaigns of education in the proper use and application of these tools and through the care and intelligence of the users themselves. The practical men in the shops have come to realize that cemented tungsten carbide is not a cure-all for every trouble as some had supposed at first, but rather a splendid high-speed tool by which production can be remarkably increased, provided it is used under the proper conditions.

They now realize that the toughest job in the shop is not necessarily the best place to judge the performance of the new tools, as the greatest savings may often be made elsewhere. They now understand that cemented tungsten carbide tools must be ground to certain angles to secure the best results, and that a design which may be suitable for high-speed-steel tools may be entirely unsuitable for tungsten carbide. They have learned that there is nothing mysterious about the new tools, and that if they are given good, strong tools with plenty of cemented tungsten carbide on the cutting edge, together with a good, rigid machine with ample power, they can duplicate the remarkable performances they have seen demonstrated. They realize that it is necessary to consider carefully the characteristics and limitations of the material and its difference from previous cutting metals, and to determine intelligently its proper application. They have seen the great benefits that others are obtaining through the use of these tools, and are seriously trying to determine all the places in their own particular shop where they can be employed to advantage.

The shop men have passed the stage of trying to buy cutting

[2] Thomas Prosser & Son, New York, N. Y., American representatives of Fried. Krupp A.-G., Essen, Germany.

tools by the pound. They realize that tungsten carbide tools have an economic place in industry, and they must be judged by what they will do, not by what they cost. Diamonds have a definite place in certain machining work and we seldom hear of a complaint because they cost $35,000 a pound. They are judged by their performance.

Some of the most important points to be remembered when using Widia tools are given below. They have been stated several times before, but will bear repeating.

Cemented tungsten carbide is comparatively tough when its great hardness is considered, but it is nevertheless only about half as strong as high-speed steel. This means that pressures which are suitable for high-speed-steel tools may be too great for tungsten carbide tools. Likewise conditions tending to result in pressures away from the supporting steel shank are to be avoided.

Machines should have plenty of strength and rigidity where needed to eliminate vibration and chatter as far as possible, and to support the tool properly. Ample power is also essential.

Machines should not be stopped with the tool in the cut and the feed on. This will not always break the tools, but there is great danger of doing so, just as with high-speed-steel tools.

Tools with larger shanks than usual should be employed, to give adequate support to the cutting edge, without danger of bending or breaking. Large, adequate cemented tungsten carbide tips should be used, as a large tip rapidly conducts the heat away from the cutting edge. However, the price of the tools tends to encourage the use of as small a tool as possible, which is an undesirable condition, and where heavy work is to be done, economizing in the size of the tool will result in disappointment. The purchase of a large, strong tool with an adequate tip will be found to pay in the long run.

Cemented tungsten carbide is a high-speed material. Its advantages can best be obtained by increasing the cutting speed in the proportion recommended by the manufacturer for the specific material being machined, and maintaining the same (or lighter) feeds used with high-speed steel. It is not intended for work with slow speeds and heavy feeds.

Proper tool angles, as recommended by the manufacturer, should be carefully observed for each particular material being machined. This is more important than in the case of former cutting materials

Careful grinding in accordance with instructions is essential, and the smoothness of the cutting edge has a very important bearing on the performance of the tools. The tools should be ground with proper clearances beneath the cutting edge, using the side of the wheel. Grinding clearances on the periphery of the wheel often gives a greater clearance than is apparent, greatly weakening the tool and shortening its life.

Cemented tungsten carbide tools seem destined to play a very important part in industry. The wonderful hardness and wear- and abrasion-resisting qualities of the material make it suitable for many applications which have up to the present time hardly been touched due to the urgency of the more important cutting tools. Such fields as surfaces for gages which must withstand abrasion, bushings and guides for constantly moving parts, punches and dies, bearings for scales and electrical meters to replace jewels, machinists' hand scrapers, grinder centers, and a host of similar applications too numerous to mention, are fertile fields for experimentation and offer large uses of cemented tungsten carbide. The application to drills, reamers, and milling cutters has endless possibilities, and even the cutting-tool applications have hardly been touched. In many large shops where there are at present only a comparatively few tools in some of the most important places, there are innumerable applications throughout the shop where tungsten carbide tools will show large savings. Many concerns are working with all possible speed to determine these places, so as to be able to reduce their costs ahead of their competitors.

Such facts can only mean that the development of cemented tungsten carbide tools is one of the milestones along the road of high-speed production.

R. E. Flanders.[3] The illustrations shown[4] of intermittent cuts on large work, particularly having the tools on the end of long extended tool holders, rather surprised me. I should like to inquire whether the cutting material has improved in the last few months or whether it is all due to the way in which the tool holder is held in the end of the long ram.

Dr. Jeffries. The work referred to by Mr. Flanders was done in the Crocker-Wheeler plant, and they did nothing but increase the rigidity of the tool. This was effected by increasing the size of the shank, and the size of the piece of cemented tungsten carbide itself, and by so mounting the piece in the shank that it would receive a maximum of support in portions which ordinarily would be in tension.

Mr. Flanders. It would appear from what Dr. Jeffries says that it is the very short-period vibrations that are destructive rather than the long-period ones. The long overhung ram would have a long period of vibration, whereas the stiffness of the tool and its support close to the piece of metal itself deals with short periods of vibration. That is evidently something for machine-tool designers to keep in mind, because it would seem—something along a similar line—that vibrations due to inaccuracies in gear teeth might be of fully as much importance in preserving the sharp edge of the tool as would the main structure of the machine itself.

W. D. Snyder.[5] Dr. Jeffries showed a photograph of one of our boring mills on which a carbon packing ring was being machined. This job formerly took about six hours, due to the necessity of regrinding the tool and the impossibility of holding the size during the complete cut. We now do the operation in about forty minutes with a Carboloy tool and the finish is much better.

G. N. Sieger.[6] Our experience in taking high-speed finishing cuts on steel has been both positive and negative, for no reason that we can assign. We attribute it to ignorance in the art. We have found, though, that the Carboloy cemented tungsten carbide seems to serve much better if a cut of, say, 0.015 in. is taken at a very high speed, rather than one of, say, 0.003 in. as a finishing cut.

Mr. Flanders. In lathe work where we are doing multiple tooling it quite often happens that we have a large flange at the end of a long shaft, or a large collar in the middle of a forging that may be two or three times the diameter of the main part of the work. If we could use high-speed steel tools on the smaller diameters of the piece on a finishing job and a Carboloy tool on the large flange and run it at the appropriate speed for the high-speed steel tool on the shaft end and let the Carboloy take the brunt of the high-speed work on the flange, we could speed up production on the whole job at a minimum expenditure for Carboloy.

S. L. Hoyt.[7] On journal bearings for large motors very light, thin shavings must be taken, leaving the surface of the journal

[3] Manager, Jones & Lamson Co., Springfield, Vt.; Manager, A.S.M.E.; Chairman of session.

[4] Prior to concluding his address, Dr. Jeffries projected on the screen the illustrations given in the preceding pages.

[5] Lieutenant Commander, Navy Yard, Boston, Mass.

[6] Carboloy Co., New York, N. Y.

[7] Research Laboratory, General Electric Company, Schenectady, N. Y.

in almost a polished condition. We have tried these tools on that job repeatedly, but never have we succeeded in getting across even one bearing, whereas the high-speed tool would do at least one. I do not believe with Mr. Sieger that a heavier cut at high speed could be used on account of the heating effect, but I cannot but believe that that particular problem will some day be overcome when we learn more about the art of applying the material.

H. D. HALL.[8] We find in some cases that we do not get a finished bore on cast iron or malleable iron with a Carboloy tool.

MR. SIEGER. We have had no trouble recently in the finishing of cast iron or malleable iron. The answer is rigidity and high speeds.

W. S. HUSON.[9] Many of those present will remember when high-speed steels were first introduced and how the same question arose as to the finishing cut. We could not get a finishing cut with high-speed steels, or, as the material was called in those days, air-hardening steel. We do get it today. Now we can get a finishing cut with Carboloy tools provided they are shaped properly and the machine tools are rigid, so reaction on the cutting edge is not excessive. We can then get almost as smooth a cut as a diamond would give, provided work is put on the cutting edge of the tool and held there. It is in a measure about the same as with a twist drill. We know very well that many drills are dulled on the edges by racing around at the bottom of the hole rather than by being pushed right into the material and taking stock out.

C. S. GOTWALS.[10] We have had some experience with Carboloy parting or cut-off tools in an automatic screw machine on a high-carbon chrome steel, and have had no success whatever in using it. I should like to know whether any one has had any success in the use of a cutting-off tool with that material.

MR. FLANDERS. Cutting-off tools are very liable to get caught and break off, owing to the chips clogging on the side of the cut after they get into depth a little way. It is probable that the high pressures to which cutting-off tools are subjected would make it inappropriate to use tungsten carbide for them, and the edge would probably crumble.

[8] Manufacturing Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa. Assoc-Mem. A.S.M.E.

[9] Carboloy Company, New York, N. Y. Mem. A.S.M.E.

[10] Time Study Engineer, Hess Bright Mfg. Co., Philadelphia, Pa. Mem. A.S.M.E.

MSP-52-4

What Information Does the Machine-Tool Buyer Need From the Machine-Tool Salesman?

By GEORGE T. TRUNDLE, JR., CLEVELAND, OHIO

THE subject assigned to me by the chairman of the Program Committee, and on which I agreed to talk, is: "What information does the machine-tool buyer need from the machine-tool salesman?" But after studying over my experience as an adviser in the purchase of large quantities of machine tools, I am going to take the privilege of setting forth some of the things that the machine-tool salesman needs from the buyer in order to serve him best.

"Who, What, When, Where, Why?"

The Cincinnati Enquirer recently published an article headed: "Who, What, When, Where, Why?" in which it was said that the first rule a newspaper reporter learns is to answer five basic questions in the lead of his story—"Who, What, When, Where, and Why?" This, the writer asserts, is a good rule for all people in buying goods. In the answers to those five questions lie the fundamental facts one should know about every article he purchases.

Under "Who" are included these questions: Who made it? Is he reliable? Is he experienced? Will he be in business if the article needs repair or replacement?

"What?" What will the article do for you? Will it improve your appearance? Will it save you time, money, effort? Will it make you more confortable, more happy?

"When?" When was it made, designed, packed? Is it fresh? Is it the newest model or latest development?

"Where?" Where can you buy it? Does your own store carry it? If not, can you place dependence on the store that does?

"Why?" Why should you buy it in preference to some similar product? Is it superior in design, materials, workmanship? Will it fit your needs more closely?

It seems that this little article covers in a few words my entire subject. While the writer in *The Enquirer* is discussing things one ordinarily would buy in a department store, the rule is good for the buying of anything; at least I hope to prove such to be the case.

What the Buyer Wants to Know in Purchasing Equipment

In the purchase of equipment: First, the buyer wants to know that the machine tool is made by a reliable firm, reliable financially as well as in ability to design and build.

Second, he wants to know that the machine is not an infringement on some one else's patent. I consider it humanly impossible for any manufacturer to say that his product is free from infringement. Therefore, the manufacturer of this machine must be financially able to protect the buyer. The buyer also has additional security if he is buying the machine from a reliable agent.

Just recently the higher courts ruled that a certain manufacturer was infringing on a patent and that he must pay a given amount of money for every machine he had manufactured and sold. It developed that the manufacturer was not financially able to meet this demand, therefore the matter was up to the buyer. Fortunately the equipment had been purchased through a reliable agent or distributer, a company which stands ready to protect its customers and which therefore paid the claim. This is one advantage of buying through a distributer rather than a direct representative of the manufacturer. Later I shall point out why I consider it better to buy through a reliable distributer.

Third, the buyer wants facts as to what can be expected from the machine in the way of production, based on facts furnished by him.

Fourth, he wants to know what delivery he can expect. The third and fourth items are the first which start argument between the buyer and the seller. Seldom does a machine-tool salesman get sufficient information from the buyer to intelligently state what production can be expected.

The production from any machine of the best design depends on the type of holding fixtures, the type of tools and the kind of material the tools are made of, the heat treating of these tools, the ability of the buyer to properly sharpen the tools, the skill of the set-up man, the skill of the operator, and the kind of cutting compound.

The salesman is often given a blueprint of the part to be machined. The blueprint will call for $^1/_{32}$, $^1/_{16}$, or $^1/_8$ in. finish. It may be a forging, it may be a casting. The casting may be hard, it may be soft. It may be full of blowholes or hard spots. The same thing may be true of the forging. It may not have sufficient stock for finish or it may have two or three times the amount specified on the blueprint. All of which has a direct bearing on the production that can be expected from the machine tool you are going to purchase.

The prudent manufacturer will make his estimate of production conservative. The reckless machine-tool salesman will assume all conditions ideal and guarantee a much higher production. The buyer is after production. He will purchase the machine promising the greatest production, or a fight, whichever you want to call it.

In the latter case the salesman has not misquoted. He is basing his facts on a blueprint which specifies ideal conditions. The buyer should, whenever possible, let the machine-tool salesman see the job for which he is buying the machine, and should give him the history of producing that part to make it suitable to be used in an assembly.

Hardly any two persons agree on the type of finish a certain part should have. The finish that is satisfactory to one may not be satisfactory to another. The drawing may call for 0.0003 in. tolerance on a reamed hole, when in reality the buyer is manufacturing the part within a tolerance of 0.002 or 0.003 in. and it is perfectly satisfactory.

As a warning to the buyer: Give the facts to the machine-tool salesman. If you are buying a machine to machine a part in accordance with the blueprint, you must expect trouble.

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[1] Trundle Engineering Company.

Address delivered at a meeting of the A.S.M.E. Machine Shop Practice Division, Cleveland, Ohio, September 30, 1929.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Referring to the fourth item: The buyer wants to know what delivery he can expect. The machine-tool salesman is called in and is given the particulars and told when he must deliver the machine. The salesman is selling on commission in most cases. He wants the business. The chances are that if he tells you the truth he will not get the business, so he agrees with your delivery, or as nearly to it as he can without getting too far from the truth.

Fifth, the buyer wants to know the range of feeds and speeds. He wants to know whether his standard equipment, such as arbors, chucks, fixtures, etc., will fit the machine. He wants to know in considerable detail the size and design of the spindle, what kind of bearings, what kind of gears, whether the machine is motor driven, belt driven, or a combination drive. He is particularly interested in knowing whether sufficient power can be applied through the belt or chain to operate the machine at its capacity.

One of the most important things he wants to know is whether the machine is properly lubricated.

Previously I have pointed out to you mechanical facts, all of which pertain to the product the salesman is presenting to the buyer.

The manufacturer of a machine tool and the agent handling machines must take more care in choosing the men for their sales departments. I find the salesman whose previous training has had to do with production and engineering is much more capable of presenting his wares in a convincing way than is one who lacks this training.

Service and Advice Required by the Buyer

The buyer of machine tools has grown into the habit of expecting free engineering advice from the machine-tool salesman, not necessarily engineering advice pertaining to the particular problem for which he is interested in buying the machine, but on general machining problems. The salesman representing the manufacturer of a machine tool is usually not so well equipped for this—because he handles only one type of machine or at the most two or three—as is the salesman representing the agent who is handling a complete line of machine tools along with a variety of labor-saving devices.

Personally, if I were buying for a manufacturing plant I should prefer dealing through a reliable agent, for the same reason as outlined in a talk by J. A. Smith, general superintendent of the General Electric Company in 1927; namely, that in one interview I could get information I desired on a lot of machines rather than on just one particular make. Again, I have found that the salesman for an agent will in most cases recommend another make of machine in preference to the one he is handling if he feels that the other machine is more suitable for the buyer's needs, as this puts him in a better standing with the buyer and strengthens his chances of getting the part of the business for which his equipment is best suited.

We are constantly called on by manufacturers to make a preliminary manufacturing set-up of a product (this product may be old or it may be new with the client) to show the cost of the product when using the most modern machines and methods, as well as the capital expenditure necessary to make such a set-up. If the product is something they are now manufacturing, we take into consideration the trade-in value of the equipment. We also take into consideration the amount of money that has been written off in the depreciation account to find how the old machine made out.

When Rebuilt Machines May Be Substituted for New

In a set-up such as this we very often find it a good policy to substitute rebuilt machinery for new on some operations in order to get the difference between the costs of the rebuilt machines and the cost of new machines to apply on some machine for a major operation. In this way we are able to purchase equipment that would not be possible otherwise.

In making such set-ups we are able to save the client many thousands of dollars by dealing through a reliable agent because of the following reasons:

First, the agent, because of the size of the order, will make more liberal allowances on the used machines.

Second, the agent usually maintains a modern rebuilt-machine department and therefore can furnish rebuilt machines under guarantees equal to new machinery.

Third, the agent is located in the vicinity of the buyer's plant and is in position to render service that it is difficult to get direct from the factory unless the factory should have an office in the vicinity of the buyer's plant.

Fourth, the agent, because of his relation to the manufacturer, can usually get more attention in deliveries than the buyer would be able to get if he was dealing direct with the manufacturer.

Please do not get the idea that I am prejudiced in favor of agents or am attempting to "sell" their plan. I am giving you this information as my experience and as something for you to think about.

Fifth, because of the salesman representing the agent having come in contact with such great varieties or complete lines of machine tools, he has an opportunity to observe many clever cutting tools, jigs, fixtures, and sequences of operations that are always interesting to the buyer and thereby to help him to reduce his manufacturing cost. These salesmen are wide awake for opportunities to be of service to the buyer.

As an illustration: Just recently a salesman from one of the large steel companies came into my office with a part made from his steel and described how slow and costly the operation of making that part from his material, or any other material, was. His question was: "Mr. Trundle, is there not some machine that will do this job better than they are doing it?" I referred to our catalog file and gave him the name of a manufacturer who made a machine that would perform the operation ten times faster than the makeshift methods used by his customer. I know that this salesman went direct to his customer with the information he had secured. I am sure that the next sale of steel to this customer will be easier. I like to call this "intangible service."

When Should Machines Be Replaced

Last Sunday night, on the National Limited, three men sat in the club car discussing business and private affairs in a tone of voice that other occupants of this car could not help overhearing. One of these men, I judged, was about 50 years old, well dressed, smoking a good cigar, and with every appearance of being prosperous. The other two were perhaps between 30 and 35 years old, looked prosperous, and seemed pleased to be in the company of such a distinguished gentleman. It was not long until the conversation revealed that the two younger men were salesmen and the older man was apparently at the head of some industry which used machine tools, or at least some sort of mechanical equipment. The older gentleman made the statement that it was his policy never to buy a machine of any kind nor make a mechanical improvement unless the cost could be saved in one year.

Most of you at this meeting today have heard that statement made by a buyer, whether the buyer is a purchasing agent or the president of the company. They apparently mean what they say, but you know and I know that this great, prosperous industrial United States was not built up on that kind of reason-

ing. The buyer who has as a fixed policy and lives up to it that he will never buy a piece of equipment unless it pays for itself in one year or less is losing money and is headed straight for bankruptcy.

When I hear the statement from some man that I know to be at the head of a given organization, I immediately call on Dun's for a financial report on that company. If the report reveals that the company's profits are decreasing, I consider the man was telling the truth. If the report reveals their profits are increasing, I know he is not telling the truth. I want to make the statement that not more than 10 per cent of the machine tools sold pay for themselves in less time than two years.

Some time ago *The American Machinist* made a survey of several thousand shops which revealed that 44 per cent of all machine tools were over 10 years old. These machine tools have now grown three years older, and no doubt a large percentage of them will produce a certain kind of product at as low cost as would the most modern machine, therefore the manufacturer need not worry about how much they are digging into his profits. But the great majority are reducing his profits to a point where it will eventually be serious.

Many industries are finding it difficult to meet competition, with the result that their business is gradually tapering off. Most of these firms conclude that they are not in a profitable field because of the competition. Their competitors may be underselling them only 5 or 10 per cent, but for them to meet this cut would mean a direct loss unless they improve their planning and manufacturing methods, and install modern equipment.

Just recently I made an investigation of two products, the demand for both of which, I was informed, was gradually decreasing. Government statistics, however, showed that there had been a gradual increase since 1914, the date to which we decided to refer. The manufacturer of these articles had sought a new field by adding other lines which required considerable engineering plus new equipment and the expenditure of large sums of money to break into the market. Had he put forth the same effort on the old product and spent half the amount of money improving it and bettering his factory conditions, he would have been in a strong financial position today rather than sitting in his office with a long face wondering whether something unforeseen would happen to carry him out of his difficulty, or whether he would lose everything.

Liquid Depreciation Reserve for Replacing Equipment

I have advocated for many years that a manufacturer keep his reserve for depreciation of equipment in liquid form so that it can be used in replacing a given piece of equipment when it has reached the end of its usefulness, or better, when it has ceased to be a money earner. If something should happen to bring this about, the machine-tool manufacturers would have to expand to produce enough machine tools to supply the demand, instead of having a few years of prosperity and a long period of no business, as has been the case in the past. The fact of the matter is that the average manufacturer is transferring his reserve from his machinery account to working capital and expansion, and using all of the profits to pay dividends. In other words, he is automatically spending the tangible assets of his business.

One of the things the buyer wants from the machine-tool salesman, but does not know it, is a continuous sermon on the subject of using his reserve for depreciation to keep the plant equipped with modern machine tools.

Most manufacturers write their machine tools off at the rate of 10 per cent per year. At this rate, at the end of 10 years the machine tools have been paid for, and they should have the money available to purchase new tools. A manufacturer operating on this basis might be able to say that the machine tool will pay for itself by the first year's savings, because the cash outlay is only the difference between the price of the new machine and the amount in reserve for depreciation, plus the trade-in value of the old machine, which will be a small amount in most cases.

In closing I want to say that the machine-tool manufacturers who are preaching modern equipment to their prospective customers must install some of this more modern equipment and modern methods in their own plants and not operate on the theory that the reason their costs are high is because labor is not efficient, for labor is just as efficient as management plans for it to be. The workers are just as efficient as the tools the management gives them with which to work. I have yet to find where excessive manufacturing costs can be attributed entirely to labor.

In summing up, let me urge that the machine-tool manufacturer and the agent train their men to talk, first, on Who, What, When, Where, and Why; then if they know of a few stunts they have observed or worked out in other plants, the buyer is usually glad to hear of them, as that is profitable knowledge.

At this point it is always advisable for the salesman to introduce his little sermon on the amount of money in reserve for depreciation and the resale value of the old machine. If he can only get the buyer to realize that he should at all times have available the cash that has been written off for depreciation to replace each machine in his plant when it has ceased to be a money maker, he has then performed a real service to the buyer, and, in addition, has become much more valuable to the company he represents as well as to himself.

Discussion

J. S. Chafee.[2] I have found in my limited selling experience that one very rarely contacts with a man who has much to do with reserves for depreciation. We should be glad to have that reserve liquid as much as the salesman would. I wonder whether any one has any idea that the salesman would be able to influence the buyer's accounting methods and management so that he would have his reserves liquid rather than tied up. I think it will have to be done in a broader way than through the salesman, and that it is perhaps at management meetings as well that this will have to be preached. As I see it, the average salesman does not have much chance to influence the buyer's accounting arrangements.

John McGeorge.[3] We hear a great deal about depreciation being written off. How many firms represented here tonight really do that? When we balance the books, does not the great bulk of the balance go either to profit or loss, and is not profit and loss at once divided among stockholders? Is there any real depreciation actually provided for? In other words, is the money that depreciation represents actually put in the bank or not?

Mr. Cochran.[4] In our company a machine does not become obsolete until the machine-tool industry has brought out a machine that will displace it, because we keep our machines in first-class condition and they are not obsolete until something has been produced that will make our goods faster.

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[2] Assistant Secretary, Brown & Sharpe Mfg. Co., Providence, R. I. Assoc-Mem. A.S.M.E.

[3] Consulting Engineer, Cleveland, Ohio. Mem. A.S.M.E.

[4] National Cash Register Company, Dayton, Ohio.

R. E. Flanders.[5] Some five or six years ago a formula was devised by the Materials Handling Division of the A.S.M.E. which answers all these questions that have been put here tonight. Last fall Professor Roe applied it with some slight modifications to the obsolescence of jigs and fixtures—how much we could afford to spend for them.

Alfred E. Beulow.[6] There seem to be quite a number of manufacturers who only use tools that cannot be purchased from distributers as maintenance or equipment to make tools with, so that I cannot quite conceive of the idea that the local distributer would be the man to go to in most cases—perhaps in standard cases.

C. O. Malpas.[7] In order to conserve effort the buyer is in a position to call in an agent representing several lines and he has the possibility of securing all that he wants in one interview, whereas if he has to call in the direct manufacturer, he will probably call in four, five, or six different persons in order to get the complete list of equipment that he needs.

Mr. Beulow. It seems one cannot get all the information he requires from one distributer, because distributers mostly are handling machines along one type. For instance, one manufacturer who is making a certain product no doubt can use standard machines, but certain other products require special machines that have no local distributors.

Mr. Malpas. The agents in your vicinity may not handle the particular tool that you want or it may be a special tool, but they may be in position to get that information for you if they are alive, want the business, and want to give you the service and sell you something that they actually have.

Wm. J. Burger.[8] In my limited experience I find that the only information you get from the agent is the information you can pick out of the circulars. If you really want to know something about the machine you must get the representative from the factory or write.

I do not believe there is any one that can rebuild a machine other than the man who built it. If any one else tries, he will make a mess of it, and no one wants that type of rebuilt machine.

I do not think any one is in better position or can give you the service you want than the manufacturer. When it comes to giving information about the performance of the machine that he is offering, the agent knows very little about it.

George F. Johnston.[9] In my experience in buying for a large company in Wisconsin I have found that the agent that we have dealt with directly in many cases has not had the information that we needed, and in stating and showing him what we needed he has had to write back to the factory to get this information, which has caused us a great deal of delay. That has been true not only in one case but in very many cases. We find that we are better able to serve the trade by knowing our particular machine and knowing what production one may obtain from it, and the feeds and speeds that can be used and the type of fixtures. We also have to furnish a great many special heads, and we find that the agent cannot answer the questions of the buyer intelligently and offer him the service of quoting directly and giving him the production figures unless he is versed on that particular machine.

Harry Barney.[10] From the little experience I have had and from what I have heard it seems that the sale of machine tools for many years gone by has been handled quite ably through dealer distributers. On special equipment, jigs, fixtures, etc., I agree that in many cases it is desirable and advisable for the manufacturer to be brought into the picture, but the dealer's salesmen are supposed to know something about the equipment they are selling. They have made an analysis of it, have spent time at the manufacturers' plant, and should be in position to know intelligently the materials that are in the machine, its productive capacity, and so forth. They are in contact with the trade every day, and know the speeds and feeds that can be maintained and the type of cutting tools that can be used to the best advantage.

As to the matter of trade-in, I believe that after a machine tool has served its purpose, it should be scrapped, and not put on the open market.

W. W. Nichols.[11] The manufacturer is called upon to give guaranteed times of production, but if the salesman were to stipulate that that guarantee was to be performed on the manufacturer's material, in the machine-tool manufacturer's shop, before delivery was made on that machine, and not left to the idiosyncrasies of some shop foreman who perhaps does not want the machine in the buyer's hands, considerable discussion would be eliminated.

E. C. Brandt.[12] Why do we get something into our minds, order it, and then want it the next day? When we get an idea, what is a reasonable time to expect a realization of that idea?

Mr. McGeorge. Why should there not be the middleman between the user of the machine and the manufacturer, just as there is the architect between the owner of a building and the builder?

There came into my own practice not very long ago this situation: I was in a Western city, and one manufacturer I know had given orders that all material should be purchased in that city. When I went through the factory I noticed that the machinery they had had been bought in Detroit and in Cincinnati, but was told most stoutly that that was bought in Los Angeles. I said to him: "Why didn't you call on me, I could have found you at least three establishments right here in the city where they had every pattern required for this work," and I told them just where they were. He said, "We called upon those very firms and they said that they had not sufficient particulars." Now there was an argument that I should interpret as a need for a consulting engineer.

Thomas R. Jones.[13] What does the buyer expect from the machine-tool salesman? Why does a buyer buy a machine tool? For production? Yes. There are a great many things he buys it for, but in the last analysis he buys it to produce something in a manner that will add the greatest amount of profit to his profit and loss statement at the end of the year.

[5] Manager, Jones & Lamson Machine Co., Springfield, Vt. Mem. A.S.M.E.

[6] Chief Engineer, Lamson & Sessions Co., Cleveland, Ohio.

[7] Trundle Engineering Co. (Mr. Malpas delivered the address under discussion in the absence of Mr. Trundle.)

[8] Works Manager, Warner & Swasey Co., Cleveland, Ohio. Mem. A.S.M.E.

[9] Production Service Engineer, Kearney & Trecker Corp., Milwaukee, Wis.

[10] Barney Machinery Co., Pittsburgh, Pa.

[11] Vice-president and Mechanical Engineer, D. P. Brown & Co., Detroit, Mich. Mem. A.S.M.E.

[12] Assistant Manager, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

[13] Vice-president and General Manager, The Harris-Seybold-Potter Co., Cleveland, Ohio.

Now if the salesman is to know the economics of that machine tool, he must know something of cost accounting, the allocation of costs, how to allocate costs of floor space, of machine tools; what depreciation means, what determines the replacement of that machine.

The salesman must have at his fingertips the points which will give the buyer the information which will enable him to set up his own information as to what that machine will cost him in the long run, or what its production will net him. In many cases the buyer does not know how to figure his costs, and it may be necessary for the salesman to do something in the way of assisting him.

L. Baker.[14] I come from one of the small concerns that look with envious eyes upon the large ones that make big savings by using high-production machines. We want to use them, too, but we cannot because we do not produce enough parts of any particular kind. In order to find out whether we could use a machine of any particular type we should have to look more to the versatility of the machine, how it is set up and how we can set it up, how many times we can set it up and still make a saving through small production, and that is a thing that we invariably ask the machine-tool representatives who call upon us, and it is almost invariably the thing that they know little or nothing about.

W. G. Thompson.[15] As regards service from jobber-dealer compared with that from the manufacturer, in our plant in Racine we are producing tractors. The last year and a half we have spent a considerable amount of money on new equipment of various kinds. At first we called in the dealers and jobbers in that section who handled these various machines, and salesmen would come in and make a few remarks, ask a few questions, and take a blueprint. In two or three weeks they would come in with but half the story, and would have to go back for a representative from the factory. The eventual result was that finally they brought along the representative from the factory the first time.

As to cost of replacement: As long as a machine will produce as economically as a new one would, it should be kept in service, provided its upkeep and repairs do not forbid.

W. J. Peets.[16] In the matter of delivery of machine tools, if we have a production schedule a couple of weeks off and have been promised an eight-weeks delivery which stretches to three months or more, it makes us much angrier than if we had been given the three-months delivery in the first place and had made some temporary arrangements for handling the operation until we got the machine. Nothing is worse than delayed deliveries when a production schedule must be met.

A machine should bring some return in a definite time and should be bought on that basis regardless of whether there is money in the obsolescence account or not; if it is warranted by what it will produce, it should be bought. If a machine is a general machine that will not be put out of business by changing your product, you can take longer to pay for it than if the machine is entirely special. You have got to consider the amount of time that your product will continue—it may be two or three years or four years—but if it is a general machine it may run for five or six years and still be a good investment; it depends entirely on the machine and what is going to be done with it.

Mr. Pflume.[17] For fifteen years I represented the Heald Machine Company in Cincinnati. For a year I have had a number of lines that I now represent as a manufacturers' agent. I find that the manufacturers of machine tools do not give their representatives enough information. Men who want to buy machines talk in terms of cross-sections, of blueprint—they want to see the inside of the machine or device that is going to give them $5 where they are only getting $1.

Invariably circulars are made up largely of photographs and it is rarely that one can discern from a photograph a detail. We do not make machinery from photographs, but from line drawings, from cross-sections, from details, and every man buying machine tools understands cross-sections and details. If you had a blueprint to scale with a few dimensions on it, then you can talk the language of engineering, and the business of selling machinery today is engineering.

Mr. Cochran. One of the discussers has spoken about the manufacturer's direct representative being able to give information more quickly than the dealer. I am going to challenge that statement. If I want production estimates, the machine-tool dealer can get that information from his plant just as easily as the direct representative of the manufacturer, because the latter has to go to his production engineering department to get that information. At the same time that I am getting information on one subject from the dealer I may get it on another subject provided he is not a salesman but a sales engineer.

A direct sales representative has to cover more territory than a dealer does and he always seems to be at the other end of his territory when we want information—which makes it necessary for us to deal directly with the plant.

George B. Blaisdell.[18] The policy adopted by the engineering department of our company for replacing equipment is as follows: Before we can buy a new machine we make a comparison of the cost of the present machine with the cost of the new machine, on a general basis. We take into consideration the depreciation on the old machine as set upon our books; the depreciation of the new machine as we estimate its life. Then we take the obsolescence, the depreciation on the old machine and distribute it for the life of the new machine. We next take into consideration the repairs of the old machine as found upon our books, and estimate the repairs and maintenance of the new machine. We then take the cost of tools—so many dies or a certain number of tools per year. We figure that cost in to the yearly cost of the operation. The next item is labor, for in most cases in a hand operation it requires more labor than in machine operation. Next compare the power cost. We total these up and get the yearly cost of the present machine, and the difference between the two is our saving by purchase of the new machine. Divide that by the cost of the new machine and get the percentage saved, and if it is not more than 25 per cent we do not consider the purchase of the machine. It has to pay for itself in at least four years.

Mr. Hathaway.[19] Our work is largely standard and largely specialized. When we lay out a job for a customer we like to send blueprints and have them approved. We sometimes wait a long while to get them back, but the customer waits just as long to get his machine. That is a point I want to bring out that the customers want our machine in a hurry, but will not send us the information in the same hurry.

[14] Production Manager, Dexter Folder Co., Pearl River, N. Y.
[15] Superintendent, Tractor Works, J. I. Case Co., Racine, Wis.
[16] Engineer in Charge of Production Methods, Singer Mfg. Co., Elizabethport, N. J. Mem. A.S.M.E.
[17] Cincinnati, Ohio.
[18] Chief Engineer, Armstrong Cork Co., Lancaster, Pa. Mem. A.S.M.E.
[19] Kingsbury Machine Works, Philadelphia, Pa.

R. H. SMITH.[20] I think we owe a great deal to the machine-tool salesman and the sales engineer. Many of them come into factories and can tell the buyer whether he needs duplex machinery, or a multiple machine, a one-purpose machine, and can furnish him with a large amount of information which he needs. Therefore I feel that the machine-tool industry owes a great debt of gratitude to this body of salesmen. They are highly trained, and at no time in the history of the machine tool have we had such a splendid body of salesmen as we have today.

MR. HAUGEN. The main difference between the consulting engineer and the sales engineer is that the latter renders his services free of charge.

May I ask that you assist the salesman to this extent, that when he wants to sell you a new machine, you will give him some of the details of your present cost of production?

MR. FLANDERS. Conditions in America will practically make consulting engineers of some of the sales force of any machine-tool firm, or the firm will go out of business, and furthermore that service is rendered free; that is another disadvantage of it, but it has to be done in order to make sales. Often the change of a slight detail will make a job a productive one, and in these days competitive conditions require that a successful machine-tool firm shall give engineering advice, getting the cost back to a certain extent in the price of the machine. I think, in general, machine-tool salesmen have to know more, they have to give a higher grade of service, and have to be on terms of more nearly professional nature with their customers than any other line of salesmen that I know of, and I am strongly for them.

[20] Massachusetts Institute of Technology, Cambridge, Mass.

E. F. DUBRUL.[21] As to the formulas, I should expect an intelligent buyer sitting down with an intelligent sales engineer to be able to work them out, for I took all the data of the problems given in Professor Roe's paper as illustrations, put them before my little twelve-year-old daughter who did not know algebra—gave her the figures for the values represented by letters, and she knew enough of arithmetic to solve them.

I believe that we can find some way of evaluating the relative merits of the different features that are built into machine tools.

If that part of the engineering profession that is working in machine-tool engineering in a definite line, whether lathes, drills, or machines of a competitive type, applied the knowledge that they must have to be intelligent engineers to the economics of the things they are putting into their machines, they could evaluate machine tools in dollars and cents per this and per that feature, just as a fire-insurance company rates a building and charges its premium according to the type of construction, hazard, and so on which they have figured out on an engineering basis.

The problem in machine-tool engineering in pricing and evaluating both for the buying and selling of machine tools would be a more complex thing than the rating of a building where they have an experience to go by that is pooled from the records of the fire-insurance companies, but I think we can do it, and some day I believe that the younger generation that is coming up in the business is going to tackle problems of that sort and be able to find out why we should put in these things, what the worth of them is, and determine what the machine will save to the user and whether it can be built for the price that can be obtained for it from the user.

[21] General Manager, National Machine Tool Builders' Associations, Cincinnati, Ohio. Assoc. A.S.M.E.

MSP-52-5

Quality Control and Production Gages

By EARLE BUCKINGHAM,[1] CAMBRIDGE, MASS.

In this paper the author discusses basic principles entering into quantity control and the use of production gages. The development of interchangeable manufacturing has many advantages and should result in economies. Considerable progress has been made by many large manufacturers. Tolerances should be as large as will result in satisfactory operation. The drawings and specifications should give tolerances. The author presents an analysis of data received from manufacturers regarding cost of inspection and percentage of scrapped parts.

INTERCHANGEABLE manufacture was discussed for many years before it was realized as a practical manufacturing system. The advantages and probable economies of making the several component parts of products such as clocks, watches, and firearms such close duplicates of each other that they might be assembled without fitting, and be interchanged from one assembled unit into another were almost self-evident. Early attempts to accomplish this consisted primarily of providing filing templets to which each part was to be matched or fitted. Thus these first examples of special productive equipment included in themselves both the manufacturing equipment and the production gages.

The inadequacy of these first crude examples of special manufacturing equipment is largely responsible for the development of most of the present-day machine tools, automatic machines, and other special manufacturing equipment. In the course of this development, as well as in the growth of the technique of this type of manufacturing, existing means of measurement were found to be inadequate. This in turn led to the development and refinement of mechanical measuring devices of many kinds. It is axiomatic that the accuracy to which work can be done depends upon the accuracy to which measurements are made because errors cannot be corrected until their nature is identified and their extent measured.

Inspection methods and the production gages used have been developed generally around particular commodities. Many measuring instruments and gages have reached a considerable degree of standardization. In general, however, the common practice is to provide limit gages for all specified limiting dimensions, and these gages are made as simple as possible without much consideration to either the relative importance of the dimension measured, its interrelation with other dimensions, or the cost of using the inspection tools. The fact that a dimension on a drawing is given with tolerances is generally assumed as sufficient reason for providing gages for it without further consideration. If drawings were always complete and precise this assumption would be correct, but the technique of dimensioning drawings with tolerances has not yet been fully developed. Considerable progress along these lines, however, has been made by several of the larger manufacturing organizations, particularly those which have extremely large rates of production to maintain.

To obtain data on normal costs of inspection, percentage of spoiled parts, etc., the author addressed letters to a wide variety of industries asking for information. All replies did not give definite figures, but some responded with comments of value. Some of these comments are as follows:

We are unable to state the proportionate cost of our product in terms of gages or inspection as we do not segregate these costs on each individual article, due to the large number of articles manufactured and the extreme variation in design.

We look upon gages and inspection in the same manner as we look upon machine tools, etc., namely, they are essential to the production of the article, and the degree of accuracy required depends, of course, upon the specific article under consideration.

Each workman, as well as tool-setter, tester, and inspector, contributes more or less in normal production to the cost of inspection. Consequently the writer is unable to give any information of value relating to gaging or inspection as proportioned against other costs, such as material, overhead, etc.

As regards percentage of scrap tolerated, our ambition is to reduce this scrap to zero, which is an ideal hardly attained in practice. We treat each article manufactured as an individual problem, and do not set any limit that might be termed allowable scrap.

Initially, with a new line of apparatus, the first consideration is not what inspection may cost, but rather that the specified performance, interchangeability, and uniformity must be met. It is the responsibility of the inspection department that these requirements shall be met with certainty. The use of gages is a great advantage, but obviously these can only be used for certain classes of work. In most cases the inspector uses the same gages that are used for manufacturing, and therefore no additional expense is incurred for the same except that of checking their accuracy. They are therewith able to inspect more quickly and accurately. This is illustrated by actual data. The lowest figures in the values given apply to the case of a product consisting entirely of machined parts using jigs, gages, etc., to the fullest extent. (Note, inspection costs without gages are about seven times as great as these costs with full equipment of gages.)

The problem of the inspection department is to perform its functions at the minimum cost. When this cost seems or is high, either due to an excessive amount of defective work or parts, or facilities for inspection or excessive variation from standard, it becomes a problem for the tool and production departments.

Whether it is cost of inspection or scrap expense, past experience in the same or a similar product, or the better performance of others, is the only dependable guide. The usual set-up is that whenever any one can show where there is an opportunity for the reduction of cost, or for a saving, their suggestions will receive consideration, and if deemed worthy will lead to a study or investigation.

The direct labor element of inspection may, of course, be a minor part of the cost of quality control. In some industries it would be small in comparison with the laboratory tests performed on raw materials; in some it would be small in comparison to the amount of product consumed in tests. Quality control, or "what price quality" is so much a part of the duty of the whole manufacturing organization, that it is impossible to estimate what proportionate share of the total cost may be attributed to it.

The amount of gaging on machine work depends on many factors. Its need decreases as the strength of the producing organization increases. It decreases with the fluency of the part in question because of the continued familiarity of the whole organization with the task. It is necessarily large where a high degree of interchangeability is necessary, or where great hazard may exist in the escape of a product not up to standard.

The percentage of scrap which one is forced to tolerate depends on what the product is, how stable the demand and therefore the organization, and many times on such elements as the weather itself.

There is some fluctuation in the figures submitted when manufacturing is continually increasing its production, necessitating the training of new men. When a factory has had production running normally for over a year, then the figures given would, in our estimation, be fair for our type of work.

The figures given do not represent the total amount of inspection work done by employees, however, nor do they cover the cost of the variety of gages used through the factory, which is considerable.

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Contributed by the Machine Shop Practice Division and presented at the Annual Meeting, New York, N. Y., Dec. 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

The greater part of our gaging is done by the operators at the points where the different steps of manufacture occur. A large number of our employees have been a long time with the company, and many of them are specialists in the particular operations they perform. Often 50 per cent of an operator's time is spent in gaging the work he produces.

The following statistics on cost of inspection represent the per cent of payroll for inspection as compared with the total payroll factory cost of the product. The per cent of scrapped parts represents the per cent of spoiled parts because of faulty workmanship or material, as compared to the total production. An attempt has been made to separate them into groups which have very similar manufacturing problems.

CLASS A Household and office appliances such as washing machines, sewing machines, calculating machines, typewriters, telephone equipment, etc.

Cost of inspection.....	from 2 per cent to 7 per cent
Scrapped parts.....	from 1/2 per cent to 5 per cent

These percentages vary in the different departments, depending upon the nature of the production methods and the design and requirements of the components involved.

CLASS B Machine tools, electric motors, turbines, etc.

Cost of inspection.....	from 5 per cent to 7 per cent
Scrapped parts.....	from 1 per cent to 7 per cent

CLASS C Automobiles, agricultural machinery, gasoline engines, etc.

Cost of inspection.....	from 4 per cent to 10 per cent
Scrapped parts.....	from 2 per cent to 7 per cent

CLASS D Standard small tools, gages, etc.

Cost of inspection.....	from 10 per cent to 20 per cent
Scrapped parts.....	from 5 per cent to 25 per cent

CLASS E Special tools, gages, fixtures, etc.

Cost of inspection.....	from 25 per cent to 50 per cent

The cost of inspection on different types of productive equipment, even in the same plant, or different parts of the product, some simple and others more intricate, varies considerably in these figures. Thus in one plant with an average inspection cost of about 7 per cent, the inspection costs in different departments vary from 2 per cent to 29 per cent. In another plant whose average inspection cost is about the same, these inspection costs vary from 1 per cent to 67 per cent in different departments.

Even on the same type of manufacturing equipment, these inspection costs vary, depending upon the requirements of the product. For example, in automatic screw machine departments, the cost of inspection on the average product may be as low as 1 per cent or 2 per cent, while on parts with very close tolerances where the product must be watched continually, this cost may increase to over 10 per cent.

One interesting example comes from a large plant manufacturing a wide variety of products. On two similar products, the first being quite completely tooled up and provided with gages for rapid inspection, while the second has a minimum of such equipment, there are the following percentages:

	First example	Second example
Cost of inspection.....	1 per cent	7 per cent
Scrapped parts.....	1/2 per cent	7 per cent

The initial gage equipment in one plant which is completely tooled up to manufacture a specialized product represents about $10 per employee, and the cost of the maintenance of these gages is about one-tenth of 1 per cent of the factory cost of production.

GENERAL PRINCIPLES

In "Modern Developments in Inspection Methods," E. D. Hall gives the following suggestions:

Inspection in general does not create but rather controls quality. Quality is conceived in the design and given substance in the materials chosen, and form in the manufacturing operations. Given good designs and materials, the manufacturing organization must be held responsible for the construction of a satisfactory commodity.

However, the executives of this branch have many opposing forces bringing pressure upon them, such as demands for quick delivery, low costs, high earnings for the operators, and quality. Since the first three are immediate and ever present, while the consequences of variations in quality are usually more remote, it follows that the first three will receive the most attention by the branch engaged in producing, and that the supervision and control of quality because of its importance can best be cared for in a separate organization.

For the same reasons, the head of the inspection work should report directly to an executive who is far enough up the line to give due weight to quality as well as to costs and production.

It should be apparent from this summary of inspection that this function of manufacturing is very closely interwoven with both the design and methods of production employed. The progress of a commodity will be traced through all stages of its manufacture from its inception as a mechanical project to the final testing that determines its successful completion.

The development of any new mechanism starts with a mental conception of some function to be performed.[2] This conception then takes detailed form, first mentally, then on paper, and finally in metal. The experimental model, if such be constructed, is usually made by the cut-and-try method. Little attention is paid in the beginning to future manufacturing requirements. The main object is to construct a mechanism that will function properly regardless of the exact design. When this end is reached, what may be called the inventive or functional design has demonstrated its success.

Before manufacturing is begun, however, a manufacturing design must be perfected which will modify the inventive design so as to allow its economical production on a large scale. Many manufacturers recognize this twofold nature of designing, and maintain a separate department for each type. Indispensable as is the original invention, it is the manufacturing design which largely determines the success or failure of a given project. This manufacturing designing necessarily continues throughout the whole course of production because of the almost infinite number of petty detailed questions involved, only a few of which can be foreseen and answered in advance. One of the important functions of an engineering department is to keep in close touch with the progress of the work in the shops, deduce general principles therefrom, and apply these principles not only to the work in hand, but also to all new work that may be developed.

Assume that the functional requirements of the mechanism are established, and that the manufacturing design has been adopted. The first concern is to test this design as far as possible. The most certain method of accomplishing this is to build a physical model. Such a model must not be confused with the experimental model, as its purpose is quite different. The experimental model shows that the mechanism will perform certain functions. The manufacturing model, if properly developed, proves that the mechanism, as modified and developed to facilitate manufacture, still retains the functional advantages of the experimental model. The manufacturing model is naturally an expensive piece of equipment, but if a large output of a new commodity is under consideration, it is money well invested. In the case of a small total output, a "pilot" mechanism is often built for this purpose, which is not set aside for future reference but is incorporated in the product itself.

Clearances are vital factors, in interchangeable manufacturing. Fits can be secured without interchangeability, but the

[2] The discussion from this point on is taken from "Principles of Interchangeable Manufacturing," by Earle Buckingham, The Industrial Press, New York, N. Y., 1921.

latter cannot be maintained without proper clearances. It is self-evident that a certain space must be left between operating parts. The minimum clearances should be as small as the assembling of the parts and their proper operation under service conditions will allow. The maximum clearances should be as great as the functioning of the mechanism permits. The variation between a maximum and a minimum clearance determines the manufacturing tolerance. It is clear then that determining at the outset the permissible clearances establishes also the extent of the tolerances which control the final inspection.

Clearances should be one of the principal considerations in developing the manufacturing design. This design should aim to allow the greatest possible amount of clearance between companion parts. The more the design lends itself to this end, the greater the economy of manufacture, and the greater the degree of interchangeability obtainable. In determining which parts of a mechanism can be made interchangeable, this matter of permissible clearance plays the largest part. A mechanism which is designed so that it cannot permit fairly liberal clearances is not a suitable one to be manufactured on a strictly interchangeable basis with the standard equipment now available. Every operating part of a mechanism must be located within reasonably close clearances in each plane. After such requirements of location are met, all other surfaces should have liberal clearances.

The general tendency in the past has been to establish manufacturing tolerances by trying to hold the product as closely as possible to a fixed size. The natural result of this policy is that the tolerances established on paper are often exceeded, yet the actual working variations remain unrecorded because it is argued that under certain conditions the original requirements might be met, and, therefore, the tolerances noted are the proper ones, even though they are not maintained. Every effort to make the recorded tolerances represent the actual working tolerances is opposed on the ground that such a procedure would lower the shop standards. As a matter of fact, it is hard to understand how anything could lower the standards of the shop more than the absolute disregard of the rules it is supposed to be obeying.[3]

There is a further argument for the acceptance of liberal tolerances. Too often in manufacturing concerns, and especially in the case of interchangeable manufacturing, one finds details being made ends in themselves rather than means to a larger end. In producing a component part, the main object should not be to demonstrate how closely a fixed size can be approached; the aim should be to construct as economically as possible a mechanism that will satisfactorily perform certain functions. The knowledge of how accurately a machining operation can be performed is indeed invaluable in making the manufacturing design, but when that design has once been completed, interest should shift to the proper functioning of the completed mechanism. Finally, it may be said that in most cases the tolerances originally fixed are increased during the process of manufacturing without detriment to the mechanism. It is rarely that a tolerance has to be reduced.

The proper minimum clearances can be determined quite readily and definitely for most cases in the early stages of the work. The manufacturing model is of great value in this respect, but the maximum clearances become established only after extended experience with the particular mechanism. In many cases the extreme maximum is never found, because, long before that point is reached, the tolerances have become so liberal that there is no need, from the standpoint of economical production, to increase them further.

Component drawings have two main functions to perform. The first is to give such information about the design, holding points, and tolerances that the manufacture of a product can be started. This does not seem like a very difficult task, but the notation of tolerances on component drawings has created new problems of interpretation that have not, as yet, been fully solved. At the present time, the language of drawings with tolerances is not altogether clear and exact.

The first tendency in introducing tolerances on drawings seems to have been to attempt to express a permissible variation on every dimension given. The results obtained in the shop depend, then, upon the particular combination of dimensions used. Different organizations using different combinations could obtain radically different results, and of the possible number of different combinations there is practically no end.

The existence of a tolerance on a drawing is an acknowledgment that variations are inevitable in the physical dimensions of the product. Any dimension given on such a drawing without a tolerance should not be construed to denote an absolute size without error, but rather to indicate either that the permissible variation for that point or surface is controlled by tolerances given on other co-related dimensions, or that the dimension is so relatively unimportant that no attempt had been made to determine its permissible variation.

In making component drawings, the effort should be made to give the dimensions and necessary tolerances so that it would be possible to lay out one, and only one, representation of the maximum metal condition and one, and only one, of the minimum metal condition. If such layouts were superimposed, the difference between them would represent the permissible variation on every surface. Any condition of the product which fell within the zone thus established should be considered as meeting the requirements of the drawing. If one will make a few such layouts, it will soon be clear to him that there are always a number of dimensions that should be given without tolerances, if drawings are to be kept consistent and intelligible.

It must be realized at the start that it is impossible in every case to give on one component drawing all the dimensions that are needed to construct the patterns, tools, gages, and other manufacturing equipment without introducing many inconsistencies. Certain dimensions could be correct if one set of holding points and one series of operations were to be used, but might be incorrect under different conditions. If the component drawings are made so that they represent the proper completed conditions, the end in view is attained. Any figures that the shop desires to use are correct if they insure this result.

It is impossible to amplify this point without entering into a prolonged discussion of the effect of using different holding or registering points in the manufacturing processes. Yet it may be of interest to know that several manufacturing plants solve this problem by adding operation drawings, which give only the specific dimensions required at a particular operation.

[3] "Precision in manufacturing is not a thing to be set on a pedestal and worshiped. It costs money and time. Where it is necessary to the proper functioning of a mechanism it is worth whatever it may cost. In most mechanisms which require close fitting there are but few critical dimensions which need to be held to close limits. For any manufacturing operation the tolerances given should be the widest which will assure satisfactory operation, but no wider. Anything closer than that is economically unsound. It is particularly unwise to place close tolerances on a drawing, and then permit deviations by special dispensation. If work outside of established tolerances is usable, it proves that the tolerance is too close and should be widened in the interest of economy. Adherence to the established tolerances can usually be assured by correctly designed limit gages. The gages should be made inside the limits but as close to them as practicable, first cost and maintenance both being considered. They should then be used as fixed limits. The 'Go' gage should go and the 'No Go' gage should not go, and no gage should be forced, otherwise its life will be short." From "Some Limitations on Manufacturing to Close Limits," by B. H. Blood.

Some of the dimensions are duplicates of those on the component drawings, while others are computed to serve their restricted purpose. This proves an effective means of recording additional information required in the manufacturing departments, which cannot be put on the component drawings without danger of misuse.

After production is well under way, the component drawings have served their first purpose. In the meantime, the actual manufacturing operations have made available a store of new information regarding the proper conditions to be maintained. It should be the second function of the component drawings to record as much of this information as possible. Conflicting information, or misinformation, should be eliminated at the same time; in short, the drawings should be revised to agree with actual conditions and requirements. It has been a great fault in the past to neglect this second function almost entirely. It is a difficult task to make the component drawings represent from the first conditions that must be maintained. In time, the shop will discover many of them, often after bitter experience, even though they have been omitted from the component drawings. Frequently, however, it happens that this information does not make its way back to the office, but is retained by the shop men among themselves. Often this is the fault of the office, which is prone to consider such information as criticism, so that the shop, after a few rebuffs, makes no further attempt to pass it along. It is most essential, however, that such information be recorded in permanent form, not only because of its value to the work in hand, but also because of its helpful application to new work in the future.

The problem of the proper dimensioning of component drawings with tolerances is strictly a mathematical one. There are a few basic principles in regard to it as fixed and simple as Newton's three laws of motion, but even more difficult at times to apply correctly. Tolerances are necessary in commercial specifications only because of inability to produce absolutely identical parts. Tolerances should show the permissible amount of variation, and the direction of such variation that is less dangerous. When a variation in either direction is equally dangerous a bilateral tolerance should be given. When a variation in one direction is more dangerous than a variation in the other, a unilateral tolerance should be given in the less dangerous direction.

Adherence to the following rules for dimensioning with tolerances will help to avoid inconsistencies with the resulting misunderstandings in the manufacturing departments:

1 Only one dimension in the same straight line can be controlled within fixed limits. This is the distance between the cutting surface of the tool and the locating or registering surface of the part being machined. Therefore it is incorrect to locate any point or surface with tolerances from more than one point in the same straight line.

2 Every part of a mechanism must be located in each plane. Every operating part must be located with proper operating clearances or allowances. After such requirements of location are met, all other surfaces should have liberal clearances.

3 Dimensions should be given between those points or surfaces that it is essential to hold in a specific relation to each other. This applies particularly to those surfaces in each plane which control the location of other component parts. Many dimensions are relatively unimportant in this respect. It is good practice in such cases to establish a common holding point in each plane and give, so far as possible, all such dimensions from these common locating points. The locating points on the drawing, the locating or registering points used for machining the surfaces, and the locating points for measuring should all be identical.

4 The initial dimensions placed on component drawings should be the exact dimension that would be used if it were possible to work without tolerances. Tolerances should be given in that direction in which variations will cause the least harm or danger. When a variation in either direction is equally dangerous, the tolerances should be of equal amount in both directions, or bilateral.

5 The initial clearance, or allowance, between operating parts should be as small as the operation of the mechanism will permit. The maximum clearance should be as great as the proper functioning of the mechanism will permit.

If careful thought is given to these component drawings, much time and effort will be saved later in the shop. If they are neglected all the future work will suffer. A large percentage of the mistakes made in the manufacturing department may be traced back to improper component drawings.

Thus far these elements which form the groundwork for the actual manufacturing operations have been discussed. The manufacturing design has been developed; it has been tested with the manufacturing model; the first guess as to the proper manufacturing tolerances has been made, and all suitable and available information has been recorded on the component drawings. The means of carrying on the work of actual production will be passed over, and the facilities that should be provided for checking the results will be considered.

There are three reasons for inspecting the product during manufacture. First, the set-up of the productive equipment should be tested before production is started. Second, spoiled parts should be eliminated as soon as possible to save the expenditure of useless effort on unserviceable pieces. Third, the finished components must be checked before assembly to eliminate the unserviceable parts, and thus insure the proper functioning of the mechanism. For these purposes gages are extensively employed.

A gage should be provided whenever its use is more economical than the use of standard measuring instruments. For example, if the total production of a certain mechanism amounts to about a dozen units, it would be gross extravagance to provide any special gages. On the other hand, if this production amounts to several thousand units, a complete set of gages is both desirable and necessary. The extent to which gages are necessary, therefore, depends in great measure upon the amount of the total production. Furthermore, gages should be provided to check only those conditions which it is essential to maintain. The nature and extent of the gages required depend upon the manufacturing conditions. In many cases, a check on one or two points is sufficient to detect any unsatisfactory results. Under varying manufacturing conditions different faults must be guarded against. Gages are a preventive and not a cure. The point to be emphasized is that they should be provided whenever their addition will result in the production of more or better components with a total expenditure of the same or less effort.

There are two kinds of gages to consider, which for want of better terms will be called limit gages and functional gages. A limit gage is one that checks a specified dimension to specified tolerances. A functional gage is one that checks the relationship of several dimensions to insure the proper functioning of the assembled mechanism. As with other manufacturing equipment, the exact design of a gage is unimportant if it fulfils the purpose simply and efficiently.

The degree of accuracy required on the gage depends upon the extent of the tolerances on the product. In all cases, on limit gages, the variation should be inside the established limits of the component. The dimensions given on component drawings are limit gage sizes. For example, the limits given for the diameter of a shaft should be interpreted to mean that such diameter must be made to satisfy ring or snap gages of the sizes specified.

Gages are an integral part of the manufacturing equipment. They comprise that part of the equipment the purpose of which is to measure the product, as distinguished from that part of the equipment, the purpose of which is to change the form of the material or to hold the part during a manufacturing operation.

Under this broad definition of a gage, it is apparent that some of the manufacturing equipment may be not only a holding device but also a gage. In fact, it is good practice to make jigs and fixtures so that an unserviceable part cannot be inserted. It often happens that when the normal manufacturing variations of certain machining processes are small and within known limits, a gage may be employed to test the size or form of the cutting tool, and not be applied directly to the product. At other times, a gage in the form of a setting block for the position of the tool is made as an integral part of the fixture. Again, some types of grinding machines are fitted with sizing devices which stop the feed of the wheel when the work has reached a predetermined size, thus practically eliminating the need of continuous inspection. Therefore, to determine the character of the gages that are required for the production of any particular part, it is necessary to consider both the requirements of the parts in question, and the other manufacturing equipment that is provided.

The actual production consists of taking the raw material and passing it through the equipment until it emerges as a finished component. The production problems are many and varied. Any part of the preceding work which has been slighted or left undone must be completed here in addition to the many tasks which are involved in the production itself. The problem of production is essentially the same in all industries. The requirements of the product should be determined first, and then suitable means of production must be selected or developed to secure the desired results. Often the exact requirements of the part or product in question are not fully established until actual production has been under way for some time. This situation imposes upon production the additional burden of unanticipated refinements in the manufacturing operations. Such, in brief, has been the history of production of almost every commodity.

The greatest problem involved in production is that most uncertain factor, human nature. The present tendency is to provide equipment that can be operated by semi-skilled labor. Equipment, however, cannot be made altogether fool-proof. The best that can be done is to arrange matters so that little or no excuse remains for making mistakes.

People thoughtlessly speak of unskilled labor. The more this problem is studied, the more it is realized that there is no place in interchangeable manufacturing for such assistance. That is, there is no task so elementary but that better and more economical results can be obtained by a certain degree of training or skill in the operator. An attempt is made to subdivide the productive operations into the most elementary tasks so that labor can be quickly trained to perform them satisfactorily. Each manufacturer is forced to train the majority of his own operators. Naturally then, the shorter the time required for this training, the sooner the results will show in the production. On the other hand, the less skill required of the operator, the more elaborate and complete the equipment must be. The amount of supervision required for both operators and equipment is also greatly increased, in both quantity and quality.

In any case, the better the training that these operators receive, the higher is the quality of the work produced. The operator should be taught to maintain the established tolerances. If the specified tolerances prove too severe in practice for economical production, they should be corrected, provided the functional requirements of the mechanism will permit. If they are not too severe, there is no excuse for violating them. The practice of adhering to the specified tolerances will do much to promote a high quality of product.

The inspection and acceptance or rejection of the components falls logically into two divisions. The first is the shop inspection which is made while the material is in process of manufacture. The object is first to test the set-up of the equipment, then by a periodic inspection of the production, to detect any changes in the set-up or defects in the equipment, and also to cull out defective work as soon as possible. The primary object here is to prevent the production of faulty parts. In the course of production, if the percentage of rejections is low and not over the normal amount, it is evidence that the requirements specified are being met, and the manufacturing facilities provided are satisfactory. If the percentage is high, it is evidence of improper conditions somewhere which should be investigated, and the trouble should be corrected at its source. Every effort should be made here to hold the product to the specified requirements.

The distinction between the testing of the manufacturing equipment and the product itself should always be kept in mind. That is, measurements made to test the accuracy of the productive equipment can be as elaborate as necessary with but little effect on the final cost of the product because such tests are required periodically. If simple methods, therefore, are not available, the more elaborate ones should be used. On the other hand, measurements that are made to test the product itself must be simple and direct to be economical.

The second division of the inspection is the final examination of the completed parts. The object of this inspection is to see that all components which will function properly are accepted, and that all unserviceable parts are rejected. This inspection is largely governed by the requirements of the components drawings, often represented by gages, and by any other specifications. It is therefore most important that these drawings give as nearly as possible the limits of parts which will function properly. Yet, as has already been noted, these drawings and specifications are incomplete at the beginning, and probably will always be so to a certain extent. Therefore a rigid adherence to the letter but not to the spirit of the drawings and specifications is unwise, as it will not aid in the acceptance of all serviceable material nor in the ultimate economy of manufacture. In addition to the written requirements, inspectors should have a certain amount of education and experience with the mechanisms involved, or with similar mechanisms, otherwise the inspection will always prove a hindrance to the main purpose.

The characteristic need for a successful inspector is a judicial mind. Since the requirements are laws, the inspection should equitably enforce them. The spirit of the requirements should be enforced in those cases where their exact expression is incomplete. If the essentials are always specified definitely and completely, it will be a fair assumption that incompletely specified conditions are relatively unimportant. Wherever possible, the requirements should be revised to make the letter and the spirit agree, but the attempt to cover every minute and unimportant detail will prove impossible in practice.

The functional requirements should be maintained in the final inspection strictly according to the specified conditions. The non-functional requirements should be handled in a more judicial manner, each case being decided on its merits. As a matter of fact, this final inspection should be in the nature of a functional inspection only. Little attention should be given here to the non-essentials other than, perhaps, a visual inspection for general quality, and some supervision of the shop inspection to see that the proper precautions are taken during the production to insure a good product. In all cases, the main effort throughout the work should be to establish, define, and maintain the essential conditions first, letting the non-essentials develop in practice. No secret, however, should be made of the fact that these non-essentials are left to work out their own salvation.

The final and complete evidence as to whether the aim has been accomplished is furnished after the mechanism has been

assembled and tested in service. If the total costs have been reasonable and the completed mechanisms assemble properly and perform satisfactorily all the required functions, it is conclusive evidence that all essentials have been mastered. On the other hand, if the costs are excessive or if the mechanism fails to assemble or to operate properly after being assembled, it is equally conclusive evidence of failure.

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Discussion

O. W. Boston.[4] The cost of inspection, as reported under the various classes A, B, and C, does not vary considerably one from another. The writer wonders, however, if in class C the cost of inspection for agricultural machinery is approximately the same as that for automobiles, gasoline engines, etc. In other words, it seems that classification B covering machine tools, electric motors, turbines, etc., would more logically include automobiles, gasoline engines, etc., of class C, and leave agricultural machinery alone in class C. Agricultural machinery is, by and large, machined less and to greater tolerances than those items mentioned in class B, and it might seem, therefore, that the cost of inspection for agricultural machinery would be different from machine tools, automobiles, etc.

The writer would like, also, to ask if any information was obtained as to the relative costs of materials used in the gages, compared to the cost of material inspected; this gage material cost to include such cost of measuring instruments and gages as are used. It would seem that the ratio of costs, of material in the gages, and the material inspected would give results quite different from the ratio of labor costs. Presumably with high production-material costs the cost of inspection gages would increase. On the other hand, the ratio might show a decrease in costs of inspection gages. It would be interesting to know these figures for the job-shop method of manufacture as compared to the mass production of a given industry such as machine tools, and also to know the value of this ratio for the different classes suggested. One can well appreciate the difficulty that the author has had in securing from a questionnaire positive and reliable data.

Edwin Smith.[5] Has the author figures available to show the relation between the cost of inspection equipment and the cost of the labor involved in inspection work and also any information regarding the cost of the maintenance of inspection tools?

Author's Closure

In reply to Professor Boston, the author would call attention to the fact that machine tools, electric motors, and turbines are generally manufactured in lots of greater or lesser amounts, while automobiles, gasoline engines, and most agricultural machinery are generally carried through on a continuous production schedule. While it is true that agricultural machinery is generally machined less and to wider tolerances than the other items mentioned, the amount of inspection also becomes correspondingly reduced so that the percentage remains about the same.

In reply to the inquiries about the costs of gages, etc., the author's only information on this subject is given in the paper. In this case the initial cost of gages amounts to about $10 per employee, while the cost of their maintenance amounts to about one-tenth of 1 per cent of the factory cost of production.

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[5] United Chromium, Inc., New York, N. Y.

MSP-52-6

Turning With Shallow Cuts at High Speeds

By H. J. FRENCH,[1] BAYONNE, N. J., and T. G. DIGGES,[2] WASHINGTON, D. C.

In this paper a method is described for testing lathe tools under shallow cuts and fine feeds. The relations are determined between the cutting speed, feed, depth of cut, and tool life for carbon and high-speed tool steels. Comparisons are made of tools of different forms and of tool life when cutting dry and with water or lard oil. Heat treatment and chemical composition of the tools are also studied, including in the case of high-speed tool steels, the effects of cobalt, nickel, molybdenum, arsenic, antimony, phosphorus, sulphur, copper, tin, aluminum, titanium, and tantalum. The results obtained under shallow cuts and fine feeds with these steels are compared with those obtained under heavy duty.

I—INTRODUCTION

MOST studies of turning have been made with relatively coarse feeds and deep cuts and it is now possible to predict, with an accuracy sufficient for many practical purposes, the cutting speeds which can be used economically in the rough turning of metals. Comparable information is not yet available for the shallow cuts used in finish turning.

The experiments described in this report relate primarily to a new method of test for lathe tools taking shallow cuts, and it was first used in a study of the effects of feed, depth, cutting liquids, and tool form upon the cutting speed to give a broad background for useful interpretation of results. The new test was then used in a study of the effect of composition and heat treatment upon the performance of carbon- and high-speed-steel tools and the results compared with those obtained in the customary rough-turning tests.

While there has recently been a tendency in machine-shop practice to replace finish turning by grinding, the discussion of a recent paper relating to the rough turning of alloy steels[3] indicated active industrial interest in test methods applicable to turning tools working at high speeds with shallow cuts and fine feeds. This is perhaps natural, since the bulk of industrial machining does not involve cutting conditions as severe as those obtaining in the usual rough-turning tests of high-speed tool steels.

II—PREVIOUS INVESTIGATIONS

It is generally believed that the methods of test developed for heavy cuts with high-speed tool steels cannot be applied successfully to the shallow cuts used in finish turning. For example, Taylor[4] cautioned investigators against using "cuts lighter than $^3/_{16}$ in. depth by $^1/_{16}$ in. feed," and stated further that "as a result of our experience we should consider practically worthless for determining laws (of cutting), all cuts that are as shallow as $^1/_{16}$ in., and we should much prefer a $^3/_{16}$-in. depth to a $^1/_8$-in. depth."

Among the reasons for these recommendations were the difficulty of maintaining constant cutting conditions with shallow cuts and the fact that when high frictional temperatures played only a minor part in the wear of the tools, as with shallow cuts, failure was not abrupt and complete, but, instead, the tools showed a gradual wearing away of the nose. This of course was reflected in a gradually changing depth of cut, and raised the question of what should be considered as tool failure. Wear of the tool nose which reduces the depth of cut by 0.001 in. is a relatively small part of the total depth usually encountered in rough turning and is of secondary importance since close adherence to dimensions is not ordinarily required. Such a change is of much greater importance in finish turning where the cuts are shallow, of the order of 0.005 to 0.010 in. or less, and where close adherence to dimensions is usually required.

The methods of test used by previous investigators for studying the gradual wear of lathe tools taking shallow cuts may be grouped under two headings: (1) direct measurements of tool wear, and (2) indirect methods of measurement.

Direct measurements of wear have been reported by Ripper and Burley[5] and Herbert.[6] In the experiments of Ripper and Burley the wear was determined by a microscope with vernier attachment. The tests, made in a lathe, were interrupted repeatedly to remove the tool from the holder and measure the wear.

Herbert's tests were made with a special tool-steel testing machine in which a tool was applied at the bottom end of a rotating tube placed in a vertical position. A heavy weight pressed the tube against a dead stop and regulated the amount of the cut. The vise in which the tool was held was mounted on knife edges and tilted as the tool wore. The tilting angle of the vise was proportional to the wear of the tool and was measured by a micrometer.

Indirect methods of measuring the wear of lathe tools have been described by Poliakoff,[7] Smith and Hey,[8] and Smith and Leigh.[9]

In the method used by Poliakoff, and also by Smith and Jinoya, the wear of the tools was determined from the corresponding increase in the diameter of the work (the bar being cut). An indicator was mounted on the tool rest immediately behind the tool and kept in continuous contact with the work. The tests were continued until the wear was greater than that selected to represent failure of the tool and the carriage moved back by hand, after stopping the test, to permit checking the changes in the depth of cut.

Smith and Hey and Smith and Leigh made use of a dynamometer for measuring the vertical forces on the tool when cutting. Tool comparisons were based on the time required for the vertical force to increase 10 per cent above its initial value. This increase was found to correspond approximately to a tool wear of 0.0015 in., and was stated to bear a distinct relation to the breakdown of the tool. In selecting the pressure on the tool as a

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[2] Associate Metallurgist, Bureau of Standards.

[3] H. J. French and T. G. Digges: "Rough Turning With Particular Reference to the Steel Cut," Trans. A.S.M.E., vol. 48 (1926), p. 533.

[4] F. W. Taylor, "On the Art of Cutting Metals," Trans. A.S.M.E., vol. 28 (1907), par. 252, p. 66.

Contributed by the A.S.M.E. Special Research Committee on the Cutting of Metals, and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers. Published with the approval of the Director, National Bureau of Standards, Washington, D. C.

[5] W. Ripper and G. W. Burley, "Cutting Power of Lathe Turning Tools," Proc. Inst. M.E., 1913, parts 3–4, p. 1067.

[6] E. G. Herbert, "The Cutting Properties of Tool Steel," *Jl. Iron & Steel Inst.*, vol. 81 (1910), p. 206.

[7] F. Poliakoff, "Cutting Tools," *The Engineer*, vol. 119 (1915), p. 275.

[8] D. Smith and I. Hey, "Report of the Lathe Tools Research Committee," Department of Scientific and Industrial Research published by His Majesty's Stationery Office, 1922; also *The Engineer*, vol. 137 (1924), p. 366.

[9] D. Smith and A. Leigh, "Lathe Tool Experiments With Fine Cuts," Proc. Inst. M.E., 1925, part 1, p. 383; also *The Engineer*, vol. 139 (1925), p. 318.

measure of tool life, these investigators disregarded the recommendations of Taylor and his associates who specifically stated that "no law can be established or formulated for cutting steel which expresses the relation between cutting speed and the pressure on the tool."

Some of the conclusions drawn from tests made by these different methods are compared in Table 1, which also gives a general idea of the conditions under which the tests were made. The investigators have taken different criteria for failure of the tools

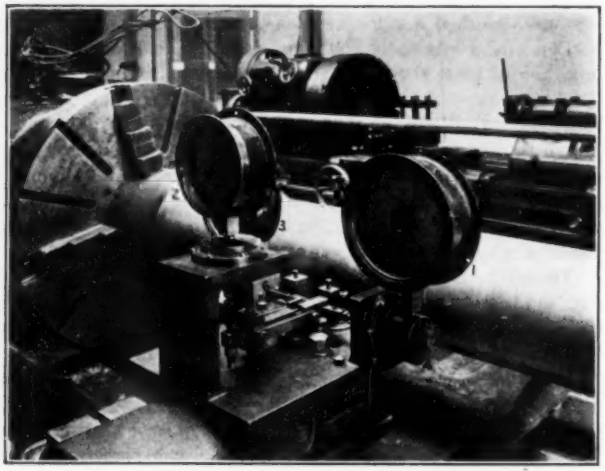


FIG. 1 DYNAMOMETER USED IN THE PRELIMINARY TOOL TESTS
(The vertical and horizontal forces are measured respectively by gage 2 and gages 1 and 3, acting through diaphragms, one of which, in its case, is indicated at 4. The diaphragms are in contact with the tool through the struts, two of which are shown at 5 and 6.)



FIG. 2 SPECIAL TOOL HOLDER USED IN THE TESTS UNDER SHALLOW CUTS AND FINE FEEDS

and have obtained what, at first glance, seem to be contradictory results. For example, Ripper and Burley found that the life of both carbon- and high-speed-steel tools, when represented by wear of 0.005 in., increased as the cutting speed decreased. Most of the other investigators referred to in Table 1 found "peaks" in the cutting speed—"tool-life" curves which showed that under some conditions increase in cutting speed resulted in an increase in the "tool life." Apparently, however, such critical speeds were found only when the working portions of the tools were kept at low temperatures by means of very shallow cuts and fine feeds, the use of cutting liquids, or both.

III—PRELIMINARY TESTS WITH A DYNAMOMETER

Tests were first made with a dynamometer with the view of correlating the changes in pressure on the tools with tool wear. The dynamometer used was similar in design and construction to that employed by Stanton and Hyde[10] and is shown in Fig. 1.

[10] T. E. Stanton and J. H. Hyde, "Forces Exerted on the Surface of Cutting Tools," Proc. Inst. M.E., 1925, part 1, p. 175.

TABLE 1 SUMMARY OF SOME OF THE RESULTS OBTAINED BY DIFFERENT METHODS OF TEST FOR LATHE TOOLS TAKING FINE CUTS

Investigator	Criterion of tool failure	Tool steel	Metal cut	Approx. range of feeds in. per rev.	Approx. range of depths in.	Coolant	Effect of cutting speed on tool life[1]	Carbon vs. high-speed tool performance	Round nose vs. broad-nose tools
Poliakoff	0.0015 in. wear (test continued to 0.002 in.)	C and high speed	0.35 C steel	0.014	0.0056	Soap and water	Life irregular with respect to cutting speed	C steel more durable than high speed	Broad nose best for C tool steel Reversed for high-speed tool steel
Smith and Jinoya	0.001 in. wear	C and high speed	Medium C steel	0.05	0.003	Soda and water	Life increases with speed	High-speed best	.....
Ripper and Burley	0.005 in. wear	C and high speed	Mild to very hard C steels	0.0275	0.020/0.120	Tested dry	For C tool steel: $V = c/A$ For high-speed steel: $V = \frac{K_1}{f^{1/2}} - (K_2 + K_3 f)d$	High speed was about ten times as good as the C steel	Tools with long cutting edges have longer life than those with short
Herbert	0.001 in. wear	C and high speed	?	0.0012 (maximum obtainable)	0.0625	Water in tube	Life irregular with respect to cutting speed	At low speeds C steel more durable than high-speed steel; at high speeds this is reversed	.....
Smith and Leigh	10 per cent increase in vertical force	C and high speed	0.35 C steel	0.0013/0.0372	0.0625 and more	Dry except in special experiments	Life irregular with light cuts; decreases continuously with speed increase for heavy cuts (0.037 feed)	At low speeds C steel as good as high-speed	.....
Smith and Hey	10 per cent increase in vertical force	High speed	0.35 C steel	0.0013	0.0625	Tested dry	Life irregular with respect to cutting speed	.....	.....

[1] V = cutting speed, f = feed, d = depth of cut, A = area of cut, and c, K_1, K_2, and K_3 are constants.

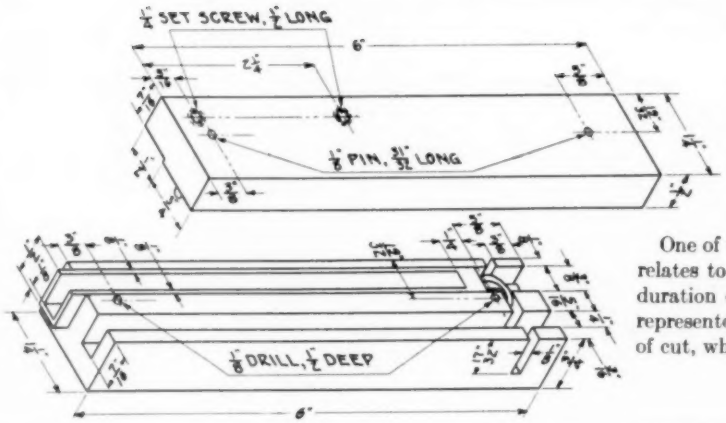


FIG. 3 SKETCH SHOWING DETAILS OF THE CONSTRUCTION OF THE SPECIAL TOOL HOLDER ILLUSTRATED IN FIG. 2

One of the disadvantages of such equipment, which was noted by earlier investigators, was the lack of rigidity of the test tools. Measurements of the diameter of the test forgings subsequent to the tool tests showed variable depths of cut from start to finish in nearly all tests. The variations were not progressive changes in one direction but appeared at irregular intervals and could be detected readily from the changes in the appearance of the cut surfaces. "Stepped cuts" were obtained in nearly all cases.

It is probable that such effects could have been minimized by refinements in the construction of the dynamometer, but since there did not seem to be any consistent relation in the preliminary tests between the vertical or horizontal forces on the tools and the tool wear, the use of the dynamometer was discontinued.

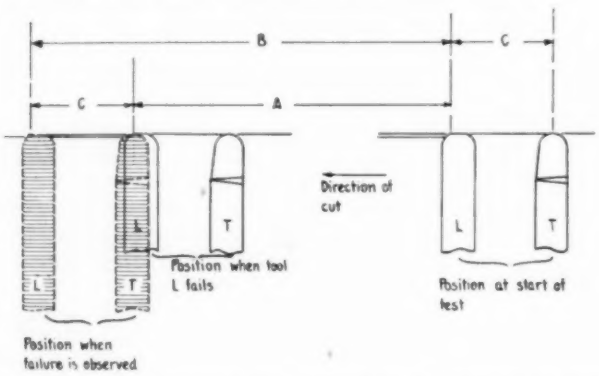


FIG. 4 DIAGRAM SHOWING CORRECTIONS TO BE APPLIED TO THE OBSERVED LENGTHS OF CUT IN THE TESTS MADE UNDER SHALLOW CUTS AND FINE FEEDS
(See text for discussion.)

IV—METHOD OF TEST USED UNDER SHALLOW CUTS

EQUIPMENT

The method of test adopted is illustrated in Fig. 2. It makes use of two tools set at equal depths in one tool holder and depends upon the fact that the "trailer" or following tool will not cut so long as the "leader" or cutting tool shows no wear.

A micrometer adjustment is provided in the groove, into which the trailer tool is placed in the tool holder as shown in Fig. 3. The leader or test tool is first clamped securely in the tool holder, which is then moved in the direction of the depth of cut until a piece of thin (cigarette) paper can just be drawn between the work and the nose of the test tool. The micrometer adjustment is then used to bring the trailer tool into a similar position, and the trailer is securely clamped in the holder by means of the setscrews shown in Fig. 3. After adjustment to equal depths, the desired depth of cut is secured by setting the carriage on the lathe in the usual manner.

One of the advantages of this method of test is its simplicity as the only special equipment required is the tool holder. Another advantage is that there is nothing to interfere with the rigidity of the test tool.

One of the disadvantages of the method is shown in Fig. 4, and relates to a correction which should be applied to the observed duration of cut. If the true length of cut of the test tool L is represented by A in Fig. 4, then B represents the observed length of cut, which differs from the true value by the amount C, repre-

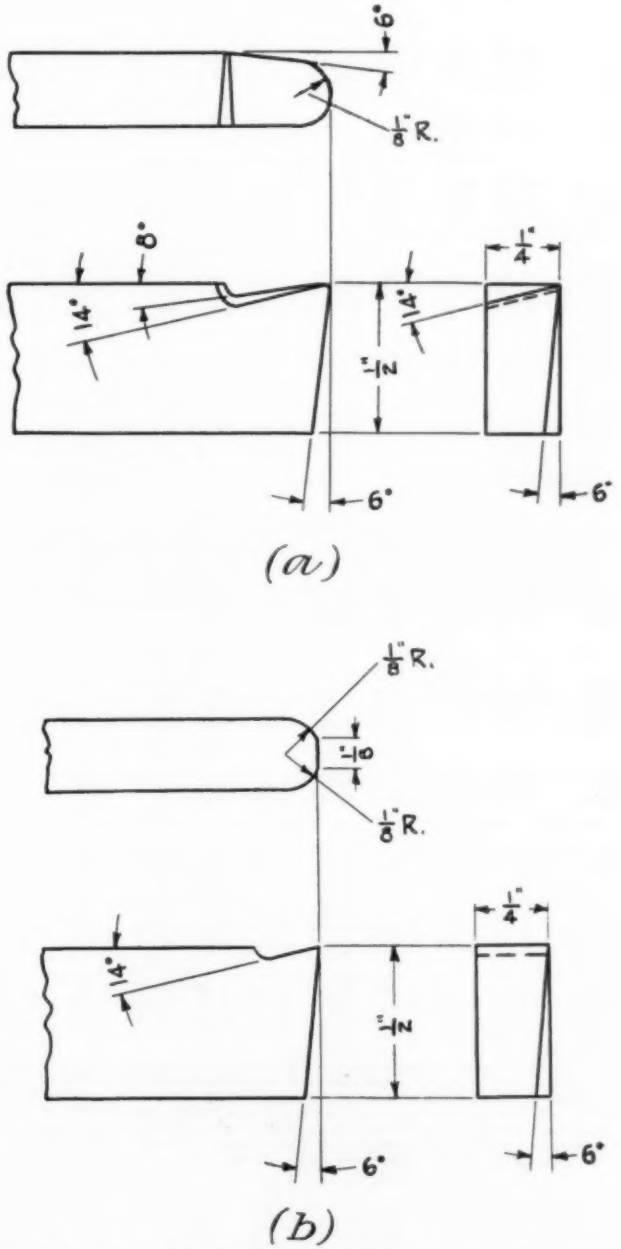


FIG. 5 FORMS AND DIMENSIONS OF THE TOOLS USED IN A MAJORITY OF THE TESTS

TABLE 2 CHEMICAL COMPOSITION AND HEAT TREATMENT OF THE TOOLS USED IN THE TESTS[1]

Steel no.	Chemical composition, per cent: C	Mn	P	S	Si	Cr	W	V	Co	Ni	Mo	Ti	Ta + Cb	Other elements as specified	Quenched[3] from, deg. fahr.	into	Tempered at, deg. fahr.	for, min.	Examd. spectroscopically
Carbon and Low-Alloy Steels																			
C14[2]	0.76	0.38	0.041	0.033	0.05	..	..	..	..	..	..	..	..	..	1450	water	250	60	..
12A[2]	0.89	0.39	0.024	0.019	..	0.05	..	..	..	0.10	..	..	..	..	1450	water	250	60	..
C2[2]	1.09	0.23	0.009	0.012	0.19	..	..	..	..	..	..	..	..	..	1425	water	250	60	..
C22[2]	1.29	0.23	0.017	0.017	0.23	0.05	..	..	..	..	..	..	..	..	1425	water	250	60	..
U[2,5]	1.0	1.20	...	...	...	0.5	0.5	..	..	..	..	..	..	..	1490	oil	250	60	..
V[2]	1.34	0.25	0.034	0.054	0.32	0.14	2.74	..	..	..	..	..	..	..	1500	10% NaCl	250	60	..
High-Speed Steels																			
Cr-W-V Steels																			
E97	0.64	0.30	0.006	0.015	0.31	3.41	13.02	1.99	..	..	..	..	..	..	2350	oil	1100	30	yes
L[5]	0.71	0.31	0.029	0.026	0.24	3.60	12.75	1.99	..	..	..	..	..	..	2350	oil	1100	30	yes
E129	0.63	0.39	0.017	0.023	0.24	3.94	13.03	2.00	..	..	..	..	..	..	2350	oil	1100	30	..
E108	0.66	0.26	0.027	0.012	0.09	3.90	18.25	1.12	..	..	0.08	..	..	..	2400	oil	1100	30	yes
I[2]	0.63	0.29	0.012	0.024	0.25	3.97	18.88	0.81	..	0.15	..	..	..	..	2400	oil	1100	30	..
D[2]	0.64	0.39	0.017	0.017	0.06	3.93	18.33	0.85	..	..	..	..	..	..	2400	oil	1100	30	..
X[2]	0.72	0.21	0.028	0.011	0.28	3.51	18.9	0.90	..	0.04	..	..	..	..	2400	oil	1100	30	..
E21	0.70	0.27	0.038	0.060	0.44	3.79	17.90	1.01	..	..	..	..	..	..	2400	oil	1100	30	..
Steels with Co																			
E15	0.76	0.37	0.048	0.115	0.63	3.75	13.55	1.99	3.68	0.22	..	..	..	..	2400	oil	1100	30	..
A[2]	0.65	0.44	0.013	0.019	0.17	4.00	14.92	1.49	3.63	0.06	..	..	..	..	2400	oil	1100	30	..
K[2]	0.60	0.12	0.008	0.026	0.12	2.95	18.23	0.99	3.50	0.09	..	..	..	..	2450	oil	1100	30	..
Steels with Co and Mo																			
CC[2]	0.69	0.17	...	...	0.34	4.23	18.32	1.53	7.8	..	0.96	..	..	..	2375[4]	oil	1050	30	..
Y[2]	0.79	0.42	0.030	0.005	0.15	4.57	21.5	1.47	11.7	..	0.61	..	..	..	2400	oil	1100	30	..
Steels with Mo																			
E109	0.61	0.18	0.027	0.009	0.04	3.34	15.44	0.81	..	..	0.74	..	..	..	2400	oil	1100	30	yes
E107	0.67	0.23	0.021	0.010	0.06	3.66	17.56	1.06	..	..	0.85	..	..	..	2400	oil	1100	30	yes
E31	0.53	0.31	0.017	0.023	0.27	3.40	11.95	1.04	..	..	3.41	..	..	..	2400	oil	1100	30	..
E29	0.71	0.33	0.013	0.019	0.44	4.74	...	0.54	..	..	7.07	..	..	..	2400	oil	1100	30	..
Steels with Ta (+Cb)																			
E43	0.62	0.30	0.016	0.016	0.23	3.75	12.30	0.02	..	..	..	..	0.44	..	2350	oil	1000	30	yes
E44	0.66	0.32	0.020	0.019	0.25	3.65	12.20	0.02	..	..	..	..	0.75	..	2350	oil	1000	30	yes
E16	0.76	0.35	0.027	0.020	0.50	3.61	11.50	0.06	..	..	..	..	5.08	..	2350	oil	1000	30	yes
E45	0.90	0.34	0.032	0.021	0.34	3.44	11.75	0.08	..	..	..	..	2.30	..	2350	oil	1000	30	yes
E100	1.42	0.32	0.007	0.013	0.29	3.37	13.03	0.10	..	..	..	..	1.10	..	2350	oil	1100	30	yes
E23	0.69	0.44	0.023	0.018	0.55	4.28	..	0.08	..	..	..	..	3.45	..	2350	oil	650	30	..
E42	0.69	0.37	0.008	0.018	0.44	4.23	8.17	1.58	..	..	..	..	6.05	..	2350	oil	1000	30	..
Steels with Ti																			
														Al					
E99	0.59	0.43	0.004	0.010	0.56	3.13	12.00	1.84	..	..	..	0.41	..	0.06	2350	oil	1100	30	yes
E87	0.69	0.42	0.024	0.015	0.73	3.87	11.94	1.68	..	..	..	1.85	..	0.30	2350	oil	1100	30	yes
E51	0.80	0.23	0.016	0.031	0.41	3.89	12.90	1.96	..	..	..	0.24	..	..	2350	oil	1100	30	yes
E96	1.24	0.54	0.018	0.015	0.81	4.37	12.70	1.92	..	..	..	0.29	..	0.08	2300	oil	1000	30	yes
E101	1.20	0.45	0.030	0.012	0.71	4.40	13.35	1.91	..	..	..	1.80	..	0.38	2300	oil	1000	30	yes
Steels with Al																			
E78	0.59	0.27	0.004	0.010	0.19	3.47	13.46	1.76	..	..	..	..	..	0.25	2350	oil	1100	30	yes
E98	0.57	0.30	0.004	0.015	0.28	3.35	13.10	1.97	..	..	..	..	..	0.78	2350	oil	1100	30	yes
Steels with Cu																			
														Cu					
E72	0.66	0.24	0.024	0.012	0.18	3.66	13.00	1.94	..	..	..	..	..	0.36	2350	oil	1100	30	yes
E73	0.65	0.31	0.021	0.011	0.18	3.61	13.15	1.92	..	..	..	..	..	0.79	2350	oil	1100	30	yes
E74	0.64	0.26	0.021	0.012	0.19	3.55	12.82	1.92	..	..	..	..	..	1.77	2350	oil	1100	30	yes
Steels with Sn																			
														Sn					
E46	0.75	0.27	0.030	0.039	0.19	3.94	12.65	1.89	..	..	..	..	...	0.15	2350	oil	1100	30	yes
E47	0.76	0.25	0.030	0.039	0.18	3.98	13.10	1.94	..	..	..	..	..	0.57	2350	oil	1100	30	yes
E48	0.68	0.22	0.020	0.036	0.35	3.97	12.85	2.11	..	..	..	..	..	1.20	2350	oil	1100	30	yes
E49	0.69	0.25	0.020	0.036	0.32	3.98	13.10	1.97	..	..	..	..	..	1.85	2350	oil	1100	30	yes
Steels with Sb																			
														Sb					
E77	0.60	0.28	0.025	0.011	0.14	3.63	12.94	1.81	..	..	..	..	..	0.41	2350	oil	1100	30	yes
E76	0.64	0.50	0.018	0.011	0.33	3.52	13.00	1.89	..	..	..	..	..	1.72	2350	oil	1100	30	yes
Steels with As																			
														As					
E70	0.64	0.25	0.029	0.013	0.16	3.66	13.08	1.78	..	..	..	..	..	0.09	2350	oil	1100	30	yes
E71	0.58	0.32	0.030	0.011	0.13	3.62	12.92	1.79	..	..	..	..	..	0.78	2350	oil	1100	30	yes
Steels with P or S																			
E131	0.64	0.39	0.058	0.022	0.24	3.94	13.03	1.96	..	..	..	..	..	..	2350	oil	1100	30	..
E132	0.66	0.39	0.020	0.135	0.24	3.94	13.03	1.96	..	..	..	..	..	..	2350	oil	1100	30	..
E133	0.67	0.39	0.018	0.215	0.24	3.94	13.03	1.96	..	..	..	..	..	..	2350	oil	1100	30	..
Steels with Ni																			
E14	0.69	0.39	0.057	0.125	0.59	3.64	13.75	1.92	..	3.70	..	..	..	..	2400	oil	1100	30	..
E130	0.61	0.39	0.017	0.023	0.24	3.94	13.03	1.90	..	3.81	..	..	..	..	2400	oil	1100	30	..
E41	0.51	0.27	0.019	0.020	0.39	3.85	12.72	1.95	..	3.54	..	..	..	..	2400	oil	1100	30	..
E22	0.61	0.24	0.043	0.073	0.55	3.66	17.40	1.02	..	3.71	..	..	..	..	2450	oil	1100	30	..

[1] The recorded heat treatments were used for the lathe tools unless otherwise indicated in the text of this report.
[2] These steels were obtained from tool-steel manufacturers; all others were experimental melts.
[3] The carbon-steel tools were first normalized by air cooling from 1500 deg. fahr. for C14 and 12A; from 1575 deg. fahr. for C2; from 1675 deg. fahr. for C22. All high-speed-steel tools were first annealed, by heating for 2 to 3 hours at 1600 deg. fahr. to 1650 deg. fahr. and furnace cooling. They were preheated for 20 min. at 1600 deg. fahr. and then held 1 1/2 min. in the high-temperature furnace at the temperatures indicated.
[4] Treated by the steel manufacturer as follows: 1500 deg. fahr., 10 min.; 2375 deg. fahr., 3 min., oil quenched.
[5] Type composition; purchased under trade name.

TABLE 3 CHEMICAL COMPOSITION, HEAT TREATMENT, AND AVERAGE MECHANICAL PROPERTIES OF THE FORGINGS CUT IN THE LATHE TESTS (TENSILE-TEST SPECIMENS TAKEN LONGITUDINALLY)

Forging no.[1]	Chemical composition, per cent C	Mn	P	S	Si	Ni	Cr	Cu[3]	Heat treatment	Prop. limit, 1000 lb. per sq. in.	Yield point, 1000 lb. per sq. in.	Tensile strength, 1000 lb. per sq. in.	Elongation in 2 in., per cent	Reduction of area, per cent
9	0.33	0.68	0.041	0.037	0.27	3.24	..	0.30	Exact treatment not known	62.7	..	96.2	24.0	51.6
12	0.29	0.85	0.032	0.040	0.26	2.58	..	0.36	Exact treatment not known	69.8	..	100.7	22.5	51.0
17 and 18	0.31	0.56	0.040	0.027	0.31	3.27	..	0.15	1460 deg. fahr., furnace cooled	51.5	53.2	87.3	29.2	54.2
36 and 37	0.40	0.74	0.028	0.039	0.24	3.32	nil	..	1600 deg. fahr., 12 hr. air to 1250 deg. fahr., held 10 hr., furnace cooled	49.8	58.4	99.2	24.5	39.8
39	0.40	0.74	0.028	0.039	0.24	3.32	nil	..	1600 deg. fahr., 12 hr. air to 1250 deg. fahr., held 10 hr., furnace cooled	54.5	56.0	92.0	15.5	47.0
40 and 41	0.34	0.56	0.032	0.032	0.21	3.30	0.05	..	1600 deg. fahr., 8 hr., air cooled 1375 deg. fahr., 8 hr., furnace cooled 1150 deg. fahr., 10 hr., furnace cooled	42.5	48.2	82.5	29.0	49.5
42[2]	0.36	0.68	0.023	0.039	0.24	3.46	0.07	..	1650 deg. fahr., 10 hr., air cooled 1300 deg. fahr., 10 hr., furnace cooled 1315 deg. fahr., 10 hr., furnace cooled 1175 deg. fahr., 10 hr., furnace cooled	..	49.2	87.5	25.6	51.0

[1] Where two forging numbers are given together the forgings were made from one heat of steel and tensile tests were made only on one of them.
[2] Tensile-test data reported by the manufacturer.
[3] Copper was not determined for forgings Nos. 36, 37, 39, 40, 41, and 42.

senting approximately the distance between the two tools. This distance is small in relation to the total length of cut only when the cutting conditions permit long life. Under such conditions the correction to be applied may be neglected since it will ordinarily be within the limits of reproducibility attained in the experiments, but the reported durations of cut have all been corrected and represent A, not B, in Fig. 4. The necessary corrections of the observed lengths of cut B, Fig. 4, can readily be applied since the rate of advance of the tools is easily determined from the speed of rotation of the test forging and the feed, both of which are ordinarily recorded in any turning tests.

Except when otherwise indicated, the test tool used under shallow cuts and fine feeds had a broad nose and was of the form and dimensions shown in Fig. 5(b). A round-nose tool, of the form and dimensions used in rough turning [Fig. 5(a)], was ordinarily used for the trailer.

Procedure

From three to six tools were tested after each of two grindings for each condition investigated, and the tests were all made in sequence. For example, in the study of the effect of cutting speed on tool performance, one tool was tested at each of the selected speeds in the series, then a second tool was tested at each of the different speeds, and this procedure repeated until the desired number of tools had been tested for each condition. Only average values are used in the comparisons made throughout this report.

Testing tools in sequence has long been practiced and tends to minimize variations in results arising from inhomogeneities in the metal being cut, which is seldom entirely uniform with respect to its machining properties. While this is important in rough turning, it appears to be of even greater importance with shallow cuts. Some very large differences were encountered in the tool performance at different parts of steel forgings, which showed very uniform tensile properties at different depths and from end to end.

The chemical compositions and the heat treatments of the tools used in all of the experiments except those in which a study was made of the effects of different hardening and tempering temperatures, are summarized in Table 2. The compositions, treatments, and properties of the test forgings are given in Table 3.

How the Carbon- and High-Speed-Steel Tools Failed

With the broad-nose tools used in the experiments the leading edge first showed wear, and the crumbling or wearing away of the nose then progressed from the leading edge to the trailing edge. This shift in the working portions of the tool from the leading to trailing edges took place slowly and could be followed quite readily in the case of most of the high-speed-steel tools. It occurred more rapidly in the carbon-steel tools, which generally were ruined very soon after the leading edge showed evidence of crumbling or spalling.

In the tests with high-speed-steel tools a groove was formed on the top surface of the tool near the leading edge, and vertical grooves were also formed on the face as shown in Fig. 6. The spacing of the grooves on the face corresponded to the feeds employed in the tests and the length of the grooves was dependent upon the depth of cut. A depression or groove was also formed on the top surface of the carbon-steel tools, but there was often no evidence of the feed grooves on the face after failure. When

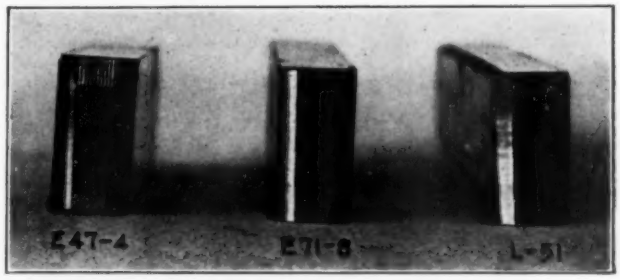


Fig. 6 New Tool and Tools Which Failed in the Tests Under Shallow Cuts and Fine Feeds

(E71-8 is a new tool. E47-4 used at 400 ft. per min. with 0.010 in. depth and 0.0115 in. per rev. feed on test forging No. 40. L51 used with 0.005 in. depth and 0.0154 in. per rev. feed at 400 ft. per min. on forging No. 40.)

visible, the feed grooves in the carbon-steel tools were not so marked as in the high-speed-steel tools.

With the method of test employed the trailer tool indicated when the leader or test tool had worn enough to produce a measurable change in the depth of cut. Experience showed that the trailer began to cut when the wear of the leader was between about 0.001 and 0.002 in., and this was considered as the point of failure of the test tools. These values apply to tests in which the two tools are originally set at equal depths, but it should be recognized that the wear representing failure may be increased by using originally a shallower setting for the trailer than for the leader. The test is therefore applicable to a wider range of conditions than those used in the experiments.

When the tools failed in a short time, it was found that wear of 0.001 or 0.002 in. was concomitant with a complete breakdown of the tool comparable to that found with deep cuts in rough turning. In other words, the nose was rubbed off to a sufficient depth to decrease the depth of cut appreciably. (See Tables 4 and 5.)

This manner of failure was characteristic of both carbon- and high-speed-steel tools, but, as already pointed out, this end point was reached at different rates in the two steels. The carbon-

TABLE 4 EFFECT OF CUTTING CONDITIONS ON THE AMOUNT OF WEAR OF THE HIGH-SPEED-STEEL TOOLS AT THE TIME AT WHICH THEY WERE CONSIDERED TO HAVE FAILED[1]

Cutting speed, ft. per min.	Feed, in. per rev.	Depth of cut, in.	Area of cut, sq. in.	Tool steel[2]	No. of tools tested	Avg. tool life, min.	Avg. decrease in depth of cut at failure, in.
400	0.0115	0.005	0.000058	E97	5	25.0	0.0010
400	0.0132	0.005	0.000066	E97	5	21.7	0.0025
400	0.0142	0.005	0.000071	E97	5	24.6	0.0025
400	0.0154	0.005	0.000077	E97	5	23.3	0.0015
400	0.0204	0.005	0.000102	E97	5	19.9	0.0010
350	0.0115	0.010	0.000115	E97	5	56.8	0.0035
350	0.0132	0.010	0.000132	E97	5	58.5	0.0060
350	0.0142	0.010	0.000142	E97	5	42.5	0.0070
350	0.0154	0.010	0.000154	E97	4	44.6	0.0035
350	0.0204	0.010	0.000204	E97	5	25.1	0.0070
380	0.0115	0.015	0.000162	E97	4	19.5	0.0135
380	0.0132	0.015	0.000198	E97	4	11.6	0.0125
380	0.0142	0.015	0.000213	E97	5	5.4	0.0125
380	0.0154	0.015	0.000231	E97	5	5.4	0.0135
380	0.0204	0.015	0.000306	E97	5	2.6	0.0150
400	0.0115	0.020	0.000230	E97	5	4.1	0.0175
400	0.0115	0.015	0.000162	E97	4	12.3	0.0130
400	0.0115	0.010	0.000115	E97	4	27.6	0.0060
400	0.0115	0.005	0.000058	E97	5	36.3	0.0015
350	0.0204	0.020	0.000408	E97	5	2.4	0.0195
350	0.0204	0.015	0.000306	E97	5	5.7	0.0135
350	0.0204	0.010	0.000204	E97	4	21.4	0.0065
350	0.0204	0.005	0.000102	E97	4	38.9	0.0015
300	0.0115	0.020	0.000230	E97	5	125.5	0.0120
350	0.0115	0.020	0.000230	E97	5	28.2	0.0175
400	0.0115	0.020	0.000230	E97	5	7.5	0.0165
450	0.0115	0.020	0.000230	E97	5	1.6	0.0170

[1] Tests were made on forging No. 40 (Table 3) with tools of the form and dimensions shown in Fig. 5(*b*).
[2] Composition and heat treatment given in Table 2.

TABLE 5 EFFECT OF CUTTING CONDITIONS ON THE AMOUNT OF WEAR OF 1.3 PER CENT C STEEL TOOLS AT THE TIME AT WHICH THEY WERE CONSIDERED TO HAVE FAILED[1]

Cutting speed, ft. per min.	Feed, in. per rev.	Depth of cut, in.	Area of cut, sq. in.	Tool steel[2]	No. of tools tested	Avg. tool life, min.	Avg. decrease in depth of cut at failure, in.
125	0.0115	0.010	0.000115	C22	1	9.4	0.0045
115	0.0142	0.010	0.000142	C22	1	10.8	0.0030
110	0.0154	0.010	0.000154	C22	1	7.5	0.0055
91	0.0204	0.010	0.000204	C22	1	35.9	0.0055
90	0.0204	0.010	0.000204	C22	1	55.2	0.0040
160	0.0115	0.005	0.000058	C22	1	11.4	0.0030
103	0.0115	0.015	0.000162	C22	1	10.3	0.0120
95	0.0115	0.020	0.000230	C22	1	10.0	0.0095
75	0.0154	0.020	0.000308	C22	1	13.9	0.0210
65	0.0204	0.020	0.000408	C22	1	11.6	0.0165
87	0.0204	0.010	0.000204	C22	1	88.2	0.0070
65	0.0204	0.020	0.000408	C22	1	74.4	0.0035
160	0.0115	0.005	0.000058	C22	2	37.5	0.0030
163	0.0115	0.005	0.000058	C22	1	1.9	0.0050
165	0.0115	0.005	0.000058	C22	1	3.2	0.0025
165	0.0115	0.005	0.000058	12A	1	12.9	0.0025
160	0.0115	0.005	0.000058	C14	1	1.0	0.0055
165	0.0115	0.005	0.000058	C14	1	24.1	0.0025
163	0.0115	0.005	0.000058	C2	1	2.5	0.0025
165	0.0115	0.005	0.000058	C2	1	0.5	0.0030

[1] Tests were made on forging No. 41 with tools of the form and dimensions shown in Fig. 5(*b*).
[2] Composition and heat treatment given in Table 2.

steel tools failed almost immediately after the leading edge of the tools showed wear, whereas the high-speed-steel tools frequently continued for some time thereafter to take a full cut.

When the tools failed completely by rubbing off of the nose, a glaze was produced on the test forging just as in the rough-turning tests and gave an additional indication of failure.

When the cutting conditions permitted the tools to cut for only a short time, the selected method of test gave an end point which was concomitant with complete failure of the tool and the trailer tool became unnecessary. Under more nearly practical conditions, when the tools continued to cut for long periods, the wear on the nose of 0.001 or 0.002 in. was seldom concomitant with complete failure. Under such conditions it became impracticable to determine the time of failure without an indicator such as the trailer tool. Tests of very short duration, which might be made in the ordinary manner, even with shallow cuts and fine feeds, are of doubtful value unless it is practicable to develop at least approximate relations between such short-time tests and the long-time cutting required in practical service. Therefore a study was made of the effects of speed, feed, and depth of cut on the durations of cut.

V—EFFECT OF CUTTING SPEED ON TOOL LIFE

High-Speed-Steel Tools

The results of tests at different cutting speeds with a feed of 0.0115 in. per revolution and depths of 0.010 or 0.020 in. are summarized in Fig. 7, and show that there was a continuous increase in the life of high-speed-steel tools as the cutting speed was decreased. Within a life range of from 2 to 125 minutes the experimental results may be represented by the equation

$$V T^n = c \qquad [1]$$

in which V is the cutting speed in feet per minute, T the tool life in minutes, and n and c are constants.

In one of the two sets of tests summarized in Fig. 7, the experimental results were most closely represented by Equation [1]

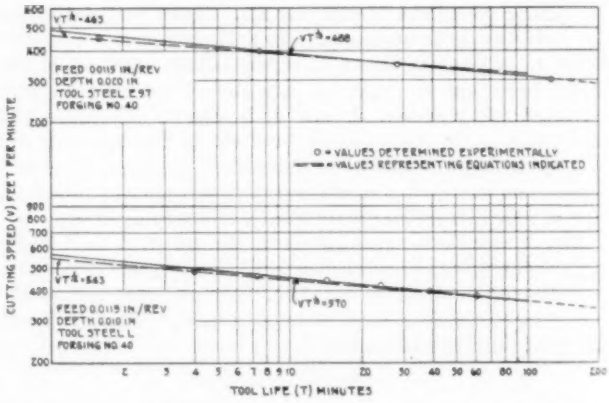


FIG. 7 RELATION BETWEEN THE CUTTING SPEED AND THE TOOL LIFE UNDER SHALLOW CUTS AND FINE FEEDS
(Tests made dry.)

when n was $^1/_{10}$, while the best representation in the second set was obtained when n was $^1/_{12}$.

When taking shallow cuts with high-speed-steel tools, Ripper and Burley[11] found that the relation between the cutting speed and tool life could be represented by Equation [1] with n equal to $^1/_{12}$. They did not report the actual values of tool life, but a study of the points plotted in their charts showed that only in some cases were the relations between cutting speed and tool life best represented by Equation [1] with $n = {}^1/_{12}$; in others, as good or better representation was obtained with $n = {}^1/_{10}$.

The value of the exponent n in Equation [1] cannot be definitely established at this time. The value $^1/_{10}$ was selected for use in this investigation since it is closer than $^1/_{12}$ to the exponent in a similar equation which Taylor demonstrated was applicable to conditions of rough turning. However, either of the quoted values should give results sufficiently accurate for practical purposes except when extrapolating to very long-time cutting from tests of relatively short duration.

Carbon-Steel Tools

The change from very short life to very long life in carbon tool steels was most often produced by decreases of less than 5 ft. per min. in the cutting speed. In the majority of the cases investigated, if the tools did not fail in less than 5 min. they continued to cut for 90 min. without sign of failure.

In general the tests were stopped after 90 min., but in a few

[11] See footnote 5.

cases tools which did not fail in this time were allowed to continue to cut for another 90 min. (total time of cutting, 3 hours) without indication of failure. This, together with the general character of the cutting-speed–tool-life curves indicated that carbon-steel tools which cut for 90 min. would, in general, cut for much longer periods such as are desired in practice.

The highest speed at which the tools would cut for 90 min. without failure was considered to represent a "critical cutting speed." It was determined by testing individual tools at successively lower cutting speeds, which differed by 2 to 5 ft. per min., until a 90-min. cut was obtained without failure.

The critical cutting speeds discussed in this report are not equal to the speeds permitting exactly 90 min. tool life, but due to the sharp increases in life with decrease in cutting speed they are so close to the latter that the two may be considered to be the same for practical purposes.

The sharp decrease in life with increase in cutting speed in the case of carbon-steel tools is probably associated with the temperatures generated at the working portions of the tools. Increase in cutting speed means increase in working temperatures, and carbon steels are known to lose hardness more rapidly with temperature rise than high-speed tool steels. The gradual change in tool life in high-speed steels is probably associated with a gradual loss in hardness with rise in temperature resulting from increase in either cutting speed, feed, or depth of cut.

VI—EFFECT OF FEED AND DEPTH OF CUT ON THE CUTTING SPEED

High-Speed-Steel Tools

A summary of the experiments with high-speed-steel tools cutting under different feeds and depths is given in Fig. 8. The relations between the cutting speed for a given tool life, the feed, and depth of cut may be represented approximately by the equation

$$V = K_1 - K_2(DF) = K_1 - K_2 A \quad \ldots\ldots [2]$$

when V is the cutting speed, D is the depth of cut, F is the feed, A is the area of cut ($=DF$), and K_1 and K_2 are constants.

With the tools and test forgings used in the experiments, as recorded in Tables 2 and 3, and a selected tool life of 90 min., Equation [2] becomes

$$V = 370 - 32\,DF \times 10^4 \quad \ldots\ldots [3]$$

For a selected tool life of 20 min. and otherwise comparable conditions, Equation [2] becomes

$$V = 430 - 38\,DF \times 10^4 \quad \ldots\ldots [4]$$

In Equations [3] and [4], V is expressed in feet per minute, D in inches, and F in inches per revolution.

Some of the plotted points are at some distance from the lines representing Equation [2] in Fig. 8, but Table 6 shows that the variations between the plotted points and the values given by Equation [2] were within ± 6 per cent. This is within the limits of reproducibility of the experiments, and is as close concordance as may be expected. As already indicated, appreciable variations were encountered in the cutting properties from point to point in the large test forgings. Likewise only minor variations from the intended depths of cut in setting the tools in the lathe represent a large percentage variation with the shallow cuts under investigation, and hence have a relatively marked effect upon the observed tool life so that reproduction of results becomes difficult.

Equation [2] indicates that the cutting speed is a function of the area of cut, and affected equally by changes in the depth and feed. This is at variance with the results of Ripper and Burley[12] for shallow cuts and those of Taylor and his associates[13] for rough turning. Ripper and Burley found that "if the area of cut is kept constant, a higher associated[14] cutting speed is obtainable when the cut is deep and the feed fine, than when the cut is shallow and the feed coarse." They expressed the relations between cutting speed, feed, and depth of cut by the following equation:

$$V = \frac{K_1}{F^{2/3}} - (K_2 - K_3 F)\,D \quad \ldots\ldots [5]$$

in which K_1, K_2, and K_3 are constants.

It is probable that the cutting speed is not affected equally by

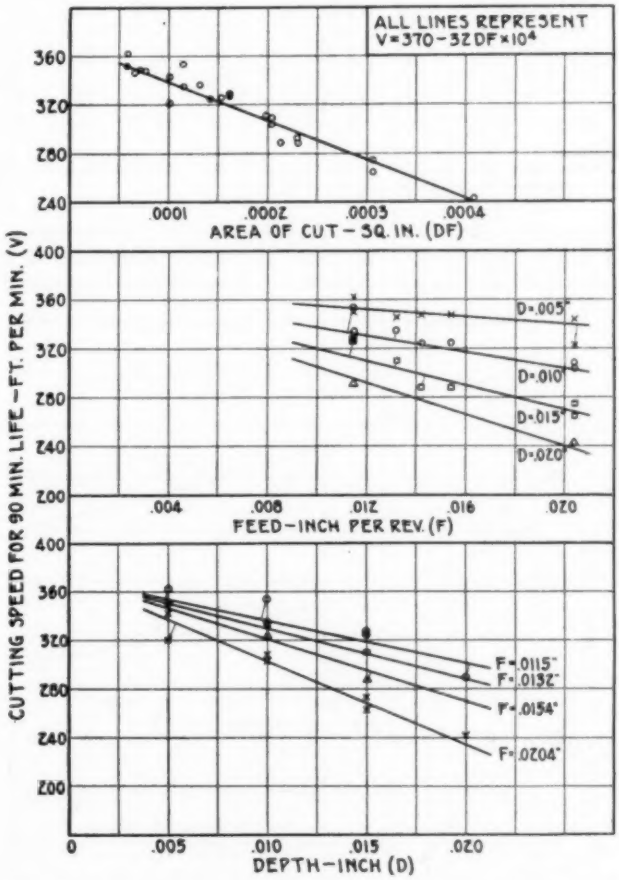


FIG. 8 EFFECT OF FEED AND DEPTH OF CUT AND THE AREA OF CUT ON THE CUTTING SPEED OF HIGH-SPEED-STEEL TOOLS WHEN TAKING SHALLOW CUTS AT FINE FEEDS

[All tests were made dry with tool steel E97 (Table 2) on forging No. 40 (Table 3).]

changes in the feed and depth of cut, but it is also probable that the differences between the true laws of cutting, and the results obtained on the assumption that the cutting speed is a function of the area of cut, will be small in the case of the shallow cuts and fine feeds here investigated.

The experiments made in this investigation using different feeds and depths of cut were not carried out with a view to establishing the laws of cutting. They were made solely to permit a more general interpretation of the results of tests designed to

[12] See footnote 5.
[13] See footnote 4.
[14] Cutting speed giving a definite tool life.

TABLE 6 EFFECT OF FEED AND DEPTH ON PERFORMANCE OF HIGH-SPEED TOOL STEEL[1]

Speed, ft. per min.	Feed, in. per rev.	Depth, in.	Area of cut, sq. in.	Tool life, minutes 1	2	3	4	5	Avg.	20 min. cutting speed (calc. from $VT^{1/10} = c$), ft. per min.	90 min. cutting speed (calc. from $VT^{1/10} = c$), ft. per min.	90 min. cutting speed (calc. from $V = \frac{370}{320{,}000DF}$), ft. per min.	Diff. between last and next to last columns in ft. per min.
400	0.0115	0.005	0.000058	30.5	26.6	22.2	24.9	20.7	25.0	410	351	351	0
400	0.0132	0.005	0.000066	18.3	25.7	19.1	19.7	25.9	21.7	405	346	349	+3
400	0.0142	0.005	0.000071	21.1	26.9	23.0	24.2	28.0	24.6	407	348	347	−1
400	0.0154	0.005	0.000077	25.4	22.3	28.4	22.1	18.4	23.3	406	347	345	−2
400	0.0204	0.005	0.000102	25.5	16.1	17.3	20.8	19.8	19.9	400	342	337	−5
350	0.0115	0.010	0.000115	54.1	59.5	58.6	51.3	60.4	56.8	385	334	333	−1
350	0.0132	0.010	0.000132	49.0	62.4	60.1	66.8	54.0	58.5	390	335	328	−7
350	0.0142	0.010	0.000142	56.5	43.6	37.6	38.2	36.5	42.5	375	324	325	+1
350	0.0154	0.010	0.000154	42.6	45.2	..	49.5	41.2	44.6	378	325	321	−4
350	0.0204	0.010	0.000204	21.9	31.2	34.8	15.0	22.6	25.1	360	308	305	−3
380	0.0115	0.015	0.000162	19.1	..	12.1	30.7	16.2	19.5	379	326	318	−8
380	0.0132	0.015	0.000198	16.9	..	9.5	9.4	10.7	11.6	360	310	307	−3
380	0.0142	0.015	0.000213	4.9	5.6	5.4	6.6	4.7	5.4	335	288	302	+14
380	0.0154	0.015	0.000231	5.9	5.2	7.1	3.6	5.0	5.4	335	288	296	+8
380	0.0204	0.015	0.000306	2.9	2.8	2.6	2.6	2.3	2.6	310	274	272	−2
350	0.0204	0.020	0.000408	2.4	2.6	3.0	1.6	2.4	2.4	281	242	239	−3
350	0.0204	0.015	0.000306	4.7	5.0	4.8	7.4	6.6	5.7	308	264	272	+8
350	0.0204	0.010	0.000204	23.2	..	20.9	22.2	19.5	21.4	351	303	305	+2
350	0.0204	0.005	0.000102	40.1	..	47.6	38.9	29.0	38.9	373	321	337	+16
400	0.0115	0.020	0.000230	3.5	3.5	4.4	4.9	4.1	4.1	341	292	296	+4
400	0.0115	0.015	0.000162	17.7	..	13.1	10.0	8.4	12.3	380	327	318	−9
400	0.0115	0.010	0.000115	29.3	..	26.9	24.9	29.2	27.6	413	354	333	−20
400	0.0115	0.005	0.000058	39.2	40.9	33.5	31.0	36.7	36.3	424	362	351	−11
												Average within	±6%

[1]Tests made with steel E97 on test forging No. 40. Composition and treatment of the tools given in Table 2. Tool form shown in Fig. 5(*b*); composition and properties of test forging given in Table 3.

throw light upon metallurgical variables such as the composition and heat treatment of the tools. From this standpoint it is immaterial whether one or another form of equation is employed

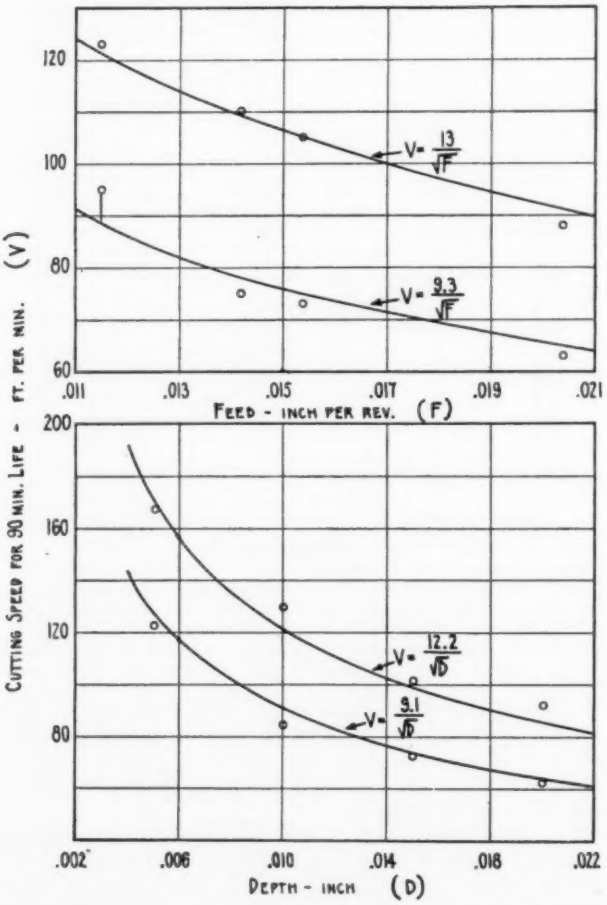


FIG. 9 EFFECT OF FEED AND DEPTH OF CUT ON THE CUTTING SPEED OF 1.3 PER CENT C STEEL TOOLS WHEN TAKING SHALLOW CUTS AT FINE FEEDS

[All tests were made dry with steel C 22 (Table 2) on forging No. 41 (Table 3).]

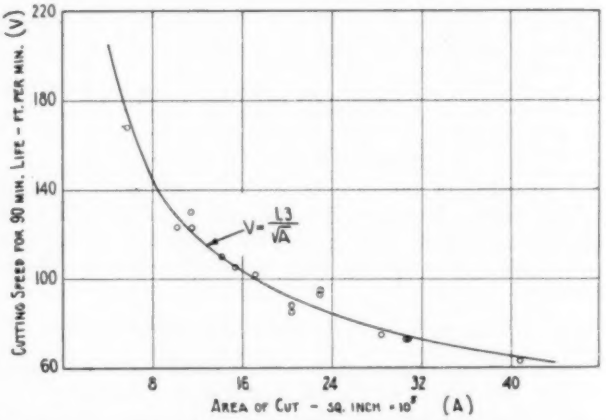


FIG. 10 EFFECT OF AREA OF CUT ON THE CUTTING SPEED OF 1.3 PER CENT C STEEL TOOLS WHEN TAKING SHALLOW CUTS AT FINE FEEDS

[All tests were made dry with steel C 22 (Table 2) on forging No. 41 (Table 3).]

so long as a reasonably close concordance is obtained between the experimental results and the calculated values. In this respect Equation [2] seems adequate for present purposes and was used in the extrapolation of experimental data as required in this investigation.

CARBON-STEEL TOOLS

The effect of feed and depth of cut on the cutting speeds of carbon-steel tools is shown in Figs. 9 and 10. In this case the relations may be represented approximately by the equation

$$V = \frac{K}{DF} = \frac{K}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots [6]$$

With the tools and the test forgings used in the experiments and the selected tool life of 90 min., Equation [6] becomes

$$V = \frac{1.3}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots [7]$$

where V is expressed in feet per minute and A in square inches.

Under the range of cutting conditions investigated, the cutting speeds for high-speed-steel tools were much higher than those for

carbon-steel tools, but the differences tended to diminish as the areas of cut were decreased. With sufficiently shallow cuts and fine feeds or with adequate cooling it may be possible for carbon-steel tools to have higher cutting speeds than high-speed-steel

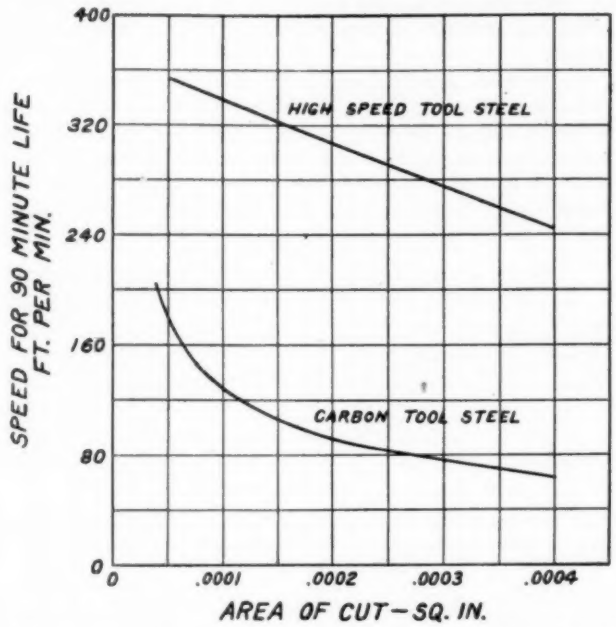


FIG. 11 COMPARISON OF THE CUTTING SPEEDS OF 1.3 PER CENT C AND THE HIGH-SPEED-STEEL TOOLS WITH DIFFERENT AREAS OF CUT
(Based on data given in Figs. 8, 9, and 10.)

tools as has been reported by some investigators.[15] This is shown graphically in Fig. 11, where the cutting speed-area of cut curve for high-speed-steel tools is a straight line and that for carbon-steel tools rises very rapidly for cuts less than about 0.0001 sq. in. The two curves may cross with sufficiently small areas of cut or if the tools are working at low temperatures through the use of cutting liquids.

VII—VARIATIONS IN TOOL FORM

SHAPE OF THE NOSE OF THE TOOL

Tests were made with tools of different forms and angles with the principal object of determining whether successful application of the described method of test was dependent upon having a broad-nose tool.

Comparisons were first made of the performance of the broad-nose tools, illustrated in Fig. 5(*b*), with tools of the forms and dimensions shown in Fig. 12. Both of the tools illustrated in Fig. 12 were similar to tools studied by the Lathe Tools Research Committee,[16] except for size, a slight increase in the front and side clearance angles and in the plan angle of the tool in Fig. 12(*a*).

The results of the tests are summarized in Table 7 and show that the tool with a plan angle of 65 deg. had a longer life (and higher cutting speed) than the broad-nose tool illustrated in Fig. 5(*b*). The sharp-pointed tool [Fig. 12(*b*)] failed immediately under the conditions of test which permitted the other two tools to cut for 20 to 35 min., but with a reduction in the cutting speed from 380 to 250 ft. per min. the sharp-pointed tools gave evidence of a measurable length of life.

The finish produced on the work appeared to be somewhat smoother and more highly polished with the broad-nose tools

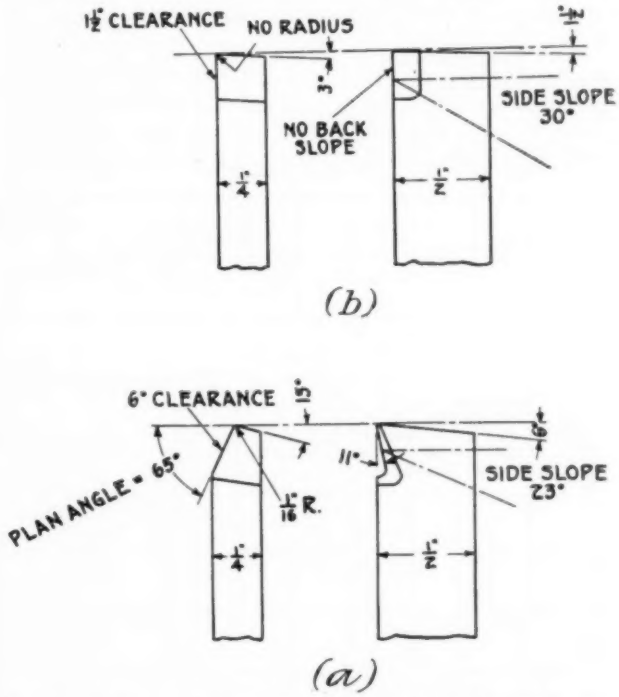


FIG. 12 TOOLS OF SPECIAL FORM USED IN SOME OF THE LATHE TESTS UNDER SHALLOW CUTS AND FINE FEEDS

[Fig. 5(*b*)] than with the tools having a 65-deg. plan angle [Fig. 12(*a*)]. The latter tools failed abruptly, whereas with the broad-nose tools, failure was progressive from leading to trailing edges, as has already been described.

Spiral chips were characteristic of the broad-nose tools, whereas straight chips and chips which were not as deeply colored were produced by the tools having the 65-deg. plan angle.

BACK SLOPE AND SIDE SLOPE IN THE BROAD-NOSE TOOLS

Further evidence that the trailer-tool method of test is applicable to a wide range of conditions is found in the results of tests made with broad-nose tools [Fig. 5(*b*)] having back slopes varying from 5 deg. to 40 deg. and side slopes of 0 deg. and 8 deg.

As shown in Fig. 13, the cutting speed of tools with 8 deg. side

[15] See Table 1.

[16] Department of Scientific and Industrial Research, Manchester Association of Engineers. Report of the Lathe Tools Research Committee, 1922, His Majesty's Stationery Office, London.

TABLE 7 PERFORMANCE OF TOOLS OF DIFFERENT FORMS WHEN TAKING SHALLOW CUTS AND FINE FEEDS[1]

Tool form	Tool life, minutes										Cutting speed for 90-min. life ft. per min.[3]
	1	2	3	4	5	6	7	8	9	Avg.	
Broad nose [Fig. 5(*b*)]	17.2	..	27.6	21.8	16.2	11.8	20.0	21.9	24.7	20.1	327
65-deg. plan angle [Fig. 12(*a*)]	43.0	28.7	40.0	22.4	44.0	20.7	37.5	28.4	..	33.1	344
Pointed tool [Fig. 12(*b*)]	0	0	0	6.7[2]	..	..	..	..	..	..	..

[1] Composition and treatment of tool steel E97 given in Table 2. Composition and properties of test forging No. 41 given in Table 3. All tests made at 380 ft. per min. cutting speed, 0.0115 in. per rev. feed, and 0.010 in. depth, except as otherwise noted.

[2] This test made at 250 ft. per min. cutting speed.

[3] Computed by Equation [1] of the text.

slope was less than that of tools with 0 deg. side slope, and the best performance of the latter was obtained with about 30 deg. back slope. With increase to 40 deg. or decrease to 5 deg. back slope the cutting speed decreased.

In addition to showing that the broad-nose tools [Fig. 5(*b*)] had a shorter life but left a more desirable finish on the work than the tools with 65 deg. plan angle and that tool angles affected the performance of the former to an appreciable degree, these tests demonstrate that the successful application of the trailer-tool method of test is not dependent upon having tools of a particular form.

VIII—EFFECT OF LARD OIL AND WATER ON THE CUTTING SPEED OF HIGH-SPEED-STEEL TOOLS

Since most industrial machining is done wet, the dry tests, already described, were supplemented by a few tests with water[17] or lard oil[18] as cutting liquids, but instead of making comparisons under one speed, feed, and depth of cut, tests were carried out at different speeds to give durations of cut from about 2 to 50 min.

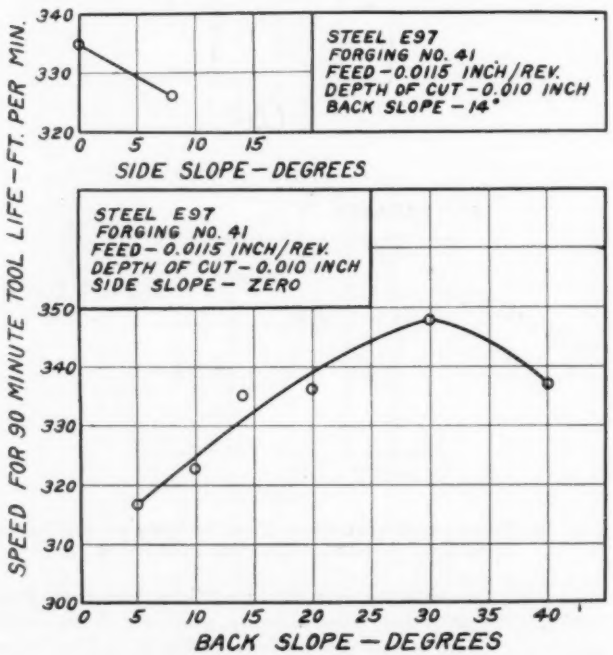


FIG. 13 EFFECT OF CHANGE IN BACK SLOPE AND IN SIDE SLOPE ON THE CUTTING SPEED OF THE BROAD-NOSE TOOLS OF FIG. 5*b* WHEN MADE OF HIGH-SPEED STEEL

A stream of the chosen liquid was thrown on the top surface of the tool through a $^1/_4$-in. nozzle at the rate of approximately 0.35 gal. per min. Alternate wet and dry tests were made to eliminate, as far as practicable, from the results variations arising from differences in the machining properties from point to point in the test forgings.

The results of the tests are summarized in Fig. 14 and show that there was a gain in the cutting speed (or tool life) from the use of either water or the lard oil. The increase was slightly greater with water than with the lard oil in tests of short duration (made with the highest cutting speeds) but equal in the tests in which tool failure occurred in about 50 min.

[17] One and one-half per cent by weight of washing soda was added to the water to minimize corrosion of the machine-tool equipment.

[18] The lard oil used was purchased under U. S. Government Master Specification No. 2d for Lubricants and Liquid Fuels. Bur. Mines Tech. Paper 323B, U. S. Department of Commerce, 1927.

In other words, the slopes of the straight lines representing the relations between cutting speed and tool life in the logarithmic plotting used in Fig. 14 were not the same for the wet and dry tests. This may be significant, although it should be noted that the differences are not much greater than the scatter of points which can ordinarily be expected with the methods of test employed.

In the tests of short duration the operating temperatures of the tools are known to have been higher than in the tests of long duration, and the gains from water, which is a more effective coolant than oils, would be expected to be greater than the gains from the lard oil. With decrease in the cutting speed the frictional temperature decreased. There was less need for cooling, and it is not unreasonable to find equal gains from the two liquids.

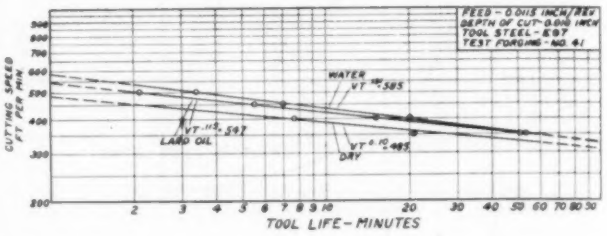


FIG. 14 RELATIONS BETWEEN THE TOOL LIFE AND THE CUTTING SPEED OF HIGH-SPEED-STEEL TOOLS WHEN CUTTING WET AND DRY
(See text for discussion.)

If it is assumed that the temperatures of the working portions of the tools at given speeds, feeds, and depths of cut decreased in order from the dry tests to tests with the lard oil and water, then it may be said that the slopes of the lines representing the experimental results in Fig. 14 increase with decrease in the operating temperatures. The three conditions may then be represented in terms of Equation [1] as follows:

For dry tests:

$$VT^{0.100} = 485 \quad [8]$$

For tests with lard oil:

$$VT^{0.115} = 547 \quad [9]$$

For tests with water:

$$VT^{0.131} = 585 \quad [10]$$

If it is further assumed that the variations in the slopes of the lines in Fig. 14 were not due entirely to experimental errors but represent the true trend of effects, and that it is justifiable to extrapolate to longer cutting periods than were obtained in the experiments, then the line representing the tests with lard oil crosses that representing the tests with water. This means that a greater gain would result from lard oil than water under the long-time cutting of commercial practice.

These features are of interest, but before they can be accepted without reservations further work should be done, and as pointed out in a recent report of The American Society of Mechanical Engineers Special Research Committee on Cutting of Metals,[19] much more must be known of the true action of cutting liquids.

Possibly the greatest benefit obtained with the liquids was the better finish produced and not the increase in tool life. In general, dry turning gave a highly polished and smooth finish at the start of the cut, but there was a tendency for the surface to become less smooth as the test progressed, resulting in a very

[19] Progress Report No. 1 on "Cooling and Lubrication of Cutting Tools," Subcommittee on Cutting Fluids, Trans. A.S.M.E., vol. 51 (1929), no. 13, paper no. MSP-51-8.

poor finish on the work piece just before tool failure. At this time there was also a tendency toward chattering, and very often small shiny particles became embedded in the work piece. The finish produced when operating with the liquids was not so highly polished at the start of the cut as when dry. However, it appeared to be as smooth, and this smoothness was maintained throughout the whole cutting time.

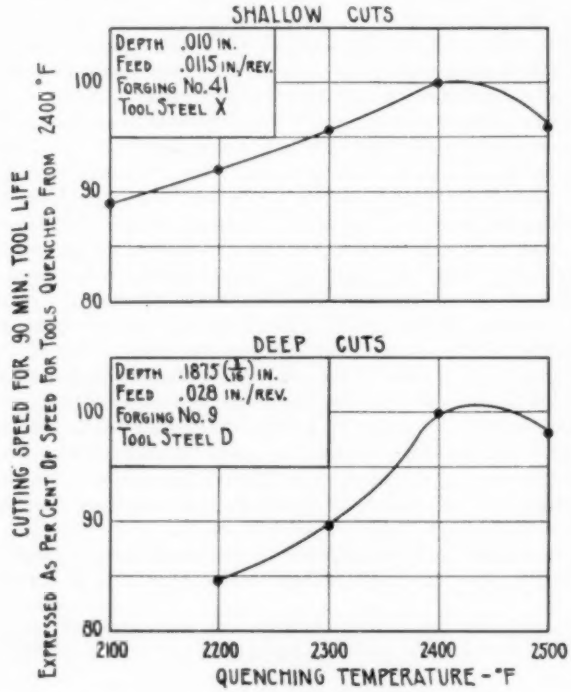


FIG. 15 EFFECT OF QUENCHING TEMPERATURE ON THE CUTTING SPEED OF HIGH-SPEED-STEEL TOOLS UNDER SHALLOW CUTS AND UNDER HEAVY DUTY

(All tools were tempered at 1100 deg. fahr. subsequent to hardening. Compositions of the tools are given in Table 2; properties of the forgings are given in Table 3. All tests were made dry.)

IX—EFFECT OF HEAT TREATMENT OF THE TOOLS ON THE CUTTING SPEED

HIGH-SPEED-STEEL TOOLS

The performance of high-speed-steel tools is quite largely dependent upon the heat treatment to which they have been subjected, and the best results are obtained in rough turning when the customary steels containing about 0.7 per cent carbon, 18 per cent tungsten, 4 per cent chromium, and 1.1 per cent vanadium are quenched from 2400 to 2450 deg. fahr. and subsequently tempered at about 1100 deg. fahr.[20] This treatment gives close to the maximum tool life, but the tools must be well supported as they are more brittle than when hardened from lower temperatures.

Tempering at 1050 to 1100 deg. fahr. subsequent to hardening from 2400 deg. fahr. may improve the tool life slightly, but a more important effect is improved toughness.

The effect of variations in the hardening temperature upon the life of roughing tools is shown in the lower half of Fig. 15, in which the cutting speeds giving 90 min. tool life are expressed as a percentage of the cutting speed of tools quenched from 2400 deg. fahr. Fig. 15 shows that the hardening treatments which gave the best results for heavy duty also gave the best results with shallow cuts and fine feeds. However, the percentage differences in the tool performance were somewhat smaller in the case of the shallow cuts than for heavy duty.

The effects of variation in tempering temperature on tool life for both deep and shallow cuts are illustrated in Fig. 16 and show that tempering at 1100 deg. fahr. tended to improve the tool performance, particularly for shallow cuts and fine feeds. This can probably be explained by the conversion to martensite of the greater part of the austenite retained upon quenching. Under shallow cuts and fine feeds, the operating temperatures are closer to atmospheric than under conditions of rough turning where the temperatures are often close to "red heat." With shallow cuts the differences in hardness between the fully martensitic steels and those containing appreciable proportions of austenite are probably maintained throughout the life of the tools and may affect their performance. Differences in hardness probably disappear under the high temperatures reached in rough turning, due to a natural "softening" of all steels with large increases in temperature, or to the automatic conversion of the austenite to martensite by the heat generated in the test, or both.

In the foregoing experiments relative to the effects of heat treatment upon the performance of the customary high-tungsten–low-vanadium high-speed tool steel, the trailer-tool method of test for shallow cuts and fine feeds gave results similar to those obtained in the breakdown or Taylor tests for rough turning. With some compositions of high-speed steel, notably in the case of that containing nickel, the rough-turning experiments and those with shallow cuts did not necessarily place the steels in the same order of performance, as will be shown in subsequent sections of this report.

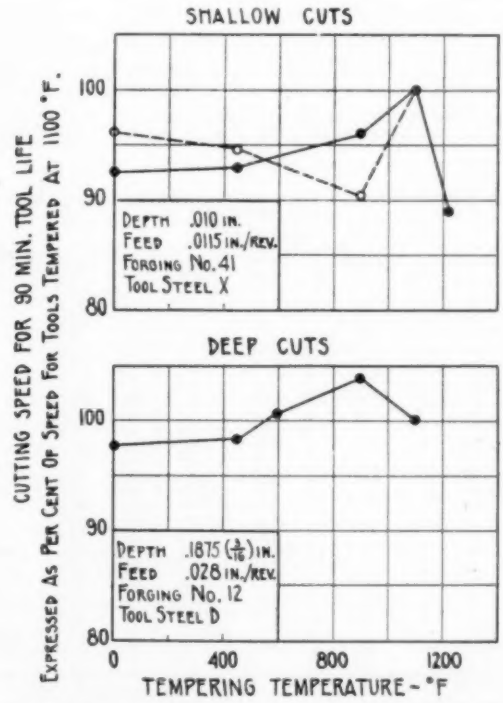


FIG. 16 EFFECT OF TEMPERING TEMPERATURE ON THE CUTTING SPEED OF HIGH-SPEED-STEEL TOOLS UNDER SHALLOW CUTS AND UNDER HEAVY DUTY

(All tools were first oil quenched from 2400 deg. fahr. Compositions of the tools are given in Table 2; properties of the forgings are given in Table 3. All tests were made dry.)

[20] H. J. French, J. Strauss, and T. G. Digges, "Effect of Heat Treatment on Lathe-Tool Performance and Some Other Properties of High-Speed Steels," Trans. Am. Soc. Steel Treating, vol. 4 (1923), p. 353.

1.3 Per Cent Carbon-Steel Tools

Tests were made of carbon-steel tools containing 1.3 per cent carbon when quenched and tempered at different temperatures, and the results are summarized in Table 8. The cutting speed was not affected to any measurable degree by variation in the hardening temperature from 1425 to 1650 deg. fahr., nor did subsequent tempering at temperatures up to 375 deg. fahr. change the performance of the untempered tools. The toughness of the tools probably varied considerably under these different heat treatments, but this is not so important with the shallow cuts and fine feeds used in the experiments as with the deep cuts and coarse feeds encountered in rough turning with high-speed steels.

TABLE 8 EFFECT OF HEAT TREATMENT ON THE PERFORMANCE OF 1.3 PER CENT C STEEL TOOLS[1]

Hardening temp.,[2] deg. fahr.	Tempering temp.,[3] deg. fahr.	Cutting speed, ft. per min.	Average tool life,[4] min.	Cutting speed giving 90 min. tool life, ft. per min.
1425	...	163	20.4	...
1425	...	161	3.2	...
1425	...	160	(90)	160
1425	250	163	1.9	...
1425	250	160	1.4	...
1425	250	160	73.7	...
1425	250	160	(90)	160
1425	375	163	47.8	...
1425	375	160	(90)	160
1425	250	165	38.0	...
1425	250	163	(90)	...
1425	250	160	(90)	163
1525	250	168	0.8	...
1525	250	165	1.1	...
1525	250	163	(90)	163
1650	250	170	3.6	...
1650	250	165	1.8	...
1650	250	163	(90)	163

[1] Tests made with steel C22 (Table 2) at 0.0115 in. per rev. feed and 0.005 in. depth of cut on forging No. 41 (Table 3).
[2] All tools normalized by heating 45 min. at 1675 deg. fahr. and cooling in still air; held 10 min. at specified hardening temperature and quenched in water.
[3] Tempered for 1 hour at specified temperatures.
[4] Bracketed values indicate that the tools did not fail in the designated time.

TABLE 9 SUMMARY OF TESTS WITH CARBON AND LOW ALLOY TOOL STEELS[1]

Steel	Chemical composition, per cent C	Mn	Cr	W	Cutting speed, ft. per min.	Feed, in. per rev.	Depth of cut, in.	Tool life, min.[3]	Speed for 90 min. life, ft. per min.
V	1.34	..	0.14	2.74	170	0.0115	0.005	4.7	...
V	1.34	..	0.14	2.74	168	0.0115	0.005	0.6	...
V	1.34	..	0.14	2.74	165	0.0115	0.005	(90)	165
U[2]	1.00	1.20	0.50	0.50	170	0.0115	0.005	2.3	...
U[2]	1.00	1.20	0.50	0.50	165	0.0115	0.005	3.2	...
U[2]	1.00	1.20	0.50	0.50	163	0.0115	0.005	20.4	...
U[2]	1.00	1.20	0.50	0.50	160	0.0115	0.005	12.7	...
U[2]	1.00	1.20	0.50	0.50	160	0.0115	0.005	1.8	...
U[2]	1.00	1.20	0.50	0.50	158	0.0115	0.005	(90)	158
C14	0.76	..	..	..	165	0.0115	0.005	24.1	...
C14	0.76	..	..	..	163	0.0115	0.005	1.0	...
C14	0.76	..	..	..	160	0.0115	0.005	(90)	...
C14	0.76	..	..	..	150	0.0115	0.005	(90)	160
12A	0.89	..	..	..	165	0.0115	0.005	12.9	...
12A	0.89	..	..	..	163	0.0115	0.005	(90)	...
12A	0.89	..	..	..	160	0.0115	0.005	(90)	...
12A	0.89	..	..	..	150	0.0115	0.005	(90)	163
C2	1.09	..	..	..	165	0.0115	0.005	0.5	...
C2	1.09	..	..	..	163	0.0115	0.005	2.5	...
C2	1.09	..	..	..	160	0.0115	0.005	(90)	160
C22	1.29	..	..	..	170	0.0115	0.005	1.5	...
C22	1.29	..	..	..	165	0.0115	0.005	3.2	...
C22	1.29	..	..	..	163	0.0115	0.005	(90)	163

[1] For compositions and heat treatments in detail, see Table 2; tests made on forging No. 41 with composition and properties given in Table 3, tool form shown in Fig. 5(*b*).
[2] Type composition—purchased under trade name.
[3] Bracketed values indicate that the tools did not fail in the designated time.

X—PERFORMANCE COMPARISONS OF DIFFERENT CARBON AND LOW-ALLOY TOOL STEELS UNDER SHALLOW CUTS

Tests were made under shallow cuts and fine feeds of carbon-steel tools containing from about 0.85 to 1.3 per cent carbon and of a low-tungsten "finishing tool steel" and a so-called non-deforming tool steel containing about 1¼ per cent manganese and small proportions of chromium and tungsten. The object of these tests was to compare the performance of the different compositions when subjected to heat treatments substantially the same as those recommended by the respective manufacturers for general purposes.

The results of the tests are summarized in Table 9 and show that the cutting speeds were nearly the same for all of the steels. The tungsten tool steel (V, Table 9) gave somewhat better performance than the manganese steel (U, Table 9) but the differences between the latter and the carbon tool steels were probably within the limits of reproducibility of the results.

The reason why the six steels tested showed comparable performance is probably to be found in the nature of the test. So long as the cutting conditions are such that the operating temperatures do not exceed certain values, which are not known at present, the tools continue to cut for long periods. With small increases in the cutting speed or other variables such as feed or depth of cut, this limiting temperature of operation is exceeded and the tools quickly fail. In other words, the test as carried out indicates the relative limits in the temperatures of operation under which the tools will stand up. Tungsten is one of the metals known to improve the resistance to "softening" of steels at high temperatures, and has probably been responsible for the slight superiority in the cutting speed of steel V, Table 9. On the other hand, the ability of steels to resist "softening" with temperature increase is probably not affected appreciably by carbon variations between 0.75 and 1.3 per cent, and the different carbon steels all showed comparable cutting speeds.

There were no detectable differences in the surfaces produced on the work piece by the different carbon- and low-alloy-steel tools.

XI—HIGH-SPEED-STEEL TOOLS OF DIFFERENT COMPOSITIONS USED UNDER SHALLOW AND DEEP CUTS

Preparation of the Steels and Tools

The chemical composition of high-speed-steel tools for rough turning was studied by Taylor and his associates[21] and has since been made the subject of many other experiments.[22–28] In fact, it is probably safe to say that continuous efforts have been made during the past twenty years to improve the performance of high-speed tool steels intended for heavy duty. Comparable studies have not been made for the shallow cuts and fine feeds which generally characterize finish-turning operations, and accordingly high-speed steels of different compositions were tested by the "trailer-tool" method described in this report and the results compared with those obtained under heavy duty. Tests were made of important industrial types of high-speed steel, such as

[21] See footnote 4.
[22] Many papers on this subject will be found in the "Bibliography of High-Speed Tool Steels" published in vol. 3 (1922) of the Trans. Am. Soc. Steel Treating, p. 47. Only a few of the more recent references are included here.
[23] H. J. French and J. Strauss, "Lathe Breakdown Tests of Some Modern High-Speed Steels," Trans. Am. Soc. Steel Treating, vol. 2 (1923), p. 1125. Bureau of Standards Tech. Papers No. 228.
[24] W. Oertel and F. Polzguter, "Beitrag zur Kenntnis des Einflusses von Kobalt und Vanadin auf die Eigenshaften von Schnellarbeitsstahl," Berichte d. Fach. des Vereins deut. Eisenhuttenleute, vol. 47 (July 17, 1924), p. 1.
[25] L. Guillet, "Les aciers á outils á coupe rapide renfermant du cobalt," *Rev. de Met.*, vol. 22 (1925), p. 88.
[26] R. Hohage and A. Grutzner, "Schneidversuche mit Schnellar beitsstahlen," *Stahl u. Eisen*, July 9, 1925, p. 1126.
[27] H. J. French and T. G. Digges, "Experiments With Nickel, Tantalum, Cobalt, and Molybdenum in High-Speed Steels," Trans. Am. Soc. Steel Treating, vol. 8 (1925), p. 681.
[28] F. C. A. H. Lantsberry, "High-Speed Steels," Trans. Am. Soc. Steel Treating, vol. 11 (1927), p. 711.

the high-tungsten–low-vanadium steels, the low-tungsten–high-vanadium steels, and the cobalt steels. A study was also made of additions of appreciable proportions of nickel, molybdenum, titanium, and tantalum, and of the effects of elements which may be classed as impurities, such as phosphorus, sulphur, arsenic, antimony, tin, copper, and aluminum.

The chemical compositions of the steels tested are recorded in Table 2, and as there indicated the majority were experimental melts, but a few commercial steels were included for comparison.

The high-speed steels were not free from all elements other than those reported in Table 2, but, in general, only small proportions of other elements were present. In one or two cases small amounts of aluminum were added to quiet the metal in the ladle. Small proportions of nickel, cobalt, or molybdenum were probably introduced through the scrap high-speed steel which formed part of the charge in some of the heats, and other elements were probably introduced inadvertently through their presence as impurities in the ferroalloys employed.

Spectroscopic examination[29] was made of samples from many of the experimental steels, and with the exception of phosphorus, sulphur, and arsenic, which are not very sensitive in arc spectra, the results confirmed those obtained by chemical analysis as reported in Table 2. In addition to these elements small proportions of impurities were found as follows: copper, aluminum, and molybdenum were found in all the steels examined, but with the exception of the steels to which these metals were intentionally added the proportions were small and considered to be below 0.03 per cent. Small proportions of tin, introduced from the ferrotantalum, were found in the tantalum steels, E44, E45, E16, and E100. Nickel was found in samples E70, E71, E77, E51, and E87. Cobalt was found in steel E51. Nickel, cobalt, and molybdenum were present in steel E51, and if 100 per cent recovery of these elements from the high-speed-steel scrap is assumed, steel E51 contained about 0.35 per cent cobalt, 0.25 per cent nickel, and 0.10 per cent or less of molybdenum.

Steels L and E97, Table 2, used as the basis of comparisons in the study of impurities, contained traces, estimated at 0.01 to 0.03 per cent, of copper and aluminum, but there was no evidence of antimony or arsenic. The most sensitive tin lines are close to iron lines, and therefore it was difficult to get a positive indication of tin which may likewise be present in traces in these two steels.

In general, only small proportions of impurities were found by spectroscopic analysis and these should not affect the comparisons to be made, particularly as steels containing different proportions of the added elements are available in most cases to show the trends in the effects produced.

In the study of impurities, the proportions of arsenic, tin, copper, etc. were much higher in most cases than the proportions which would ordinarily be encountered in commercial high-speed steels, but it is frequently advantageous to deal with extremes so as to emphasize the effects of important variables. It should also be kept in mind that the phosphorus, sulphur, arsenic, antimony, copper, or tin were not residual but were added to the steels in the ladle, and that the effects produced may differ from those observed when the corresponding elements are carried through all stages of manufacture from the ores or introduced into the steels in other ways. Nevertheless the ladle additions made constitute a logical step in the study of the subject of impurities.

The steels produced experimentally were melted in an indirect arc furnace. The molten steel was generally tapped hot enough to permit its being held in the ladle for a few moments before casting into 55-lb. ingots having a top section about 3 in. × 3 in. and a length of 22 in. A split iron mold was used in which the ratio of mold weight to ingot weight was about 1.9; in practically all cases hot tops were used and a top discard made of about 25 per cent.

[29] Examinations made by Dr. W. F. Meggers, Chief of the Spectroscopy Section.

TABLE 10 FERROALLOYS USED IN MAKING SOME OF THE SPECIAL HIGH-SPEED TOOL STEELS

Ferroalloy	Chemical composition, per cent[1]									
	C	Mn	Si	Al	Ti	Ta	Cb	Mo	W	Sn
Carbon-free ferrotitanium	..	..	2.0	5.9	25.5	..	..	..	..	...
Ferrotantalum	0.21	2.54	3.4	...	..	72.2	8.9	..	..	0.1
Ferromolybdenum[2]	0.23	..	..	...	..	..	...	59.6	..	...
Ferrotungsten containing molybdenum[3]	0.07	..	0.14	...	..	..	...	4.0	85.1	...

[1] As reported by the manufacturer.
[2] P = 0.057 per cent; S = 0.19 per cent.
[3] Made from California scheelite ore.

The required amounts of metallic antimony, arsenic, copper, tin, or aluminum were placed in the ladle and the molten steel poured on top. Phosphorus and sulphur were introduced into the steels by ladle additions of ferrophosphorus containing about 25 per cent phosphorus and pyrite (FeS). The titanium and tantalum were added to the metal in the furnace by placing the required amounts of their respective ferroalloys in sheet-steel containers and pushing these below the surface of the bath about 5 min. before tapping. The recovery varied but did not exceed about 50 per cent of the titanium added as carbon-free ferrotitanium of the composition shown in Table 10.

With the exception of steel E51, the steels containing titanium also contained aluminum, which was introduced by the ferroalloys used. It was largely on this account that two steels, E78 and E98, Table 2, were made with aluminum additions. Any marked effects produced by titanium could then be determined by comparison of the steels containing both titanium and aluminum with those containing only aluminum.

In one case about 97 per cent of the tantalum was recovered when using low-carbon ferrotantalum, but in general the recovery was appreciably less, varying from about 60 to 80 per cent. As will be noted from Table 10, the ferrotantalum used contained roughly 1 part of columbium for every eight parts of tantalum. While the steels made will be referred to as tantalum steels, it is to be understood that they also contain columbium. This element, if recovered in the same proportions as tantalum, is present in the steels in amounts equal to about one-ninth of the total percentages given in Table 2.

Molybdenum additions were made in the furnace with the original charge by means of ferromolybdenum of the compositions given in Table 10. However, in two cases, those of heats E107 and E109 (Table 2), the molybdenum was introduced as an impurity in the ferrotungsten (Table 10). Cobalt was added in a shot or cube form in the furnace with the original charge, while nickel was added as shot or electrolytic nickel in the furnace or in the ladle.

After casting, the ingots were allowed to become cold and were then annealed. Surface imperfections were removed on a shaper or surface grinder. Steels with heat numbers between E14 and E51, inclusive (Table 2), were forged with a steam drop hammer to $^3/_4$-in. × $1^1/_4$-in. bars; all other steels were forged to 2-in. × 2-in. bars under a press and then rolled into $1^1/_2$-in. × $1^1/_2$-in. bars. Forging and rolling temperatures were kept between about 2150 and 1800 deg. fahr. Subsequent to forging or rolling the bars were again annealed by heating 2 to 3 hours at 1600 to 1650 deg. fahr., and slowly cooling in the furnace.

Test tools about 5 in. long, with a cross-section of $^1/_2$ in. × $^1/_4$ in., were machined from the rolled or forged bars, and care was taken in grinding the nose to have the top surface of the finished tool comprised of metal adjacent to the surfaces of the hot-finished bars.

The tools were preheated for 20 min. at around 1600 deg. fahr.

introduced into the high-temperature furnace and kept there $1^1/_2$ min. and then quenched in a thin oil. These were subsequently tempered 30 to 45 min. at temperatures given in Table 2. The results described in Section IX of this report and earlier work[30] form the basis of selection of the hardening temperatures used which are recorded in Table 2. In most cases these are known to produce close to the best performance of which the several steels are capable. This does not apply to the steels containing tantalum nor to the commercial steels containing the highest

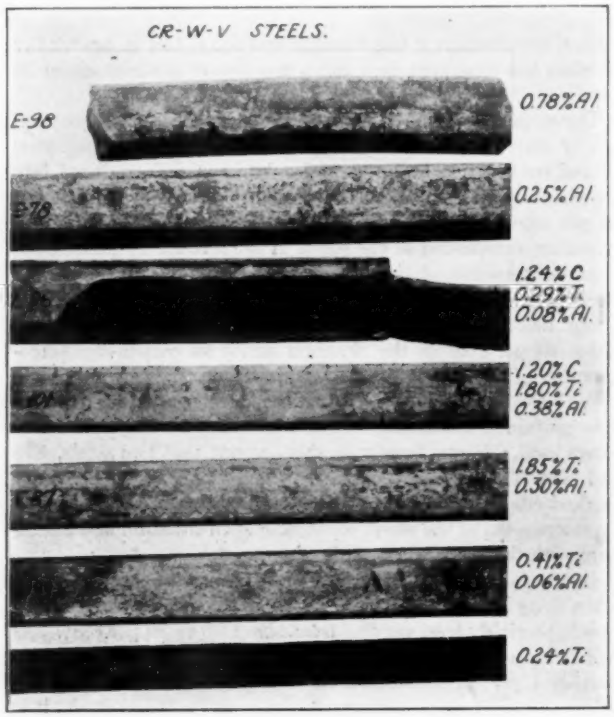


FIG. 17 APPEARANCE OF SOME OF THE ROLLED OR FORGED HIGH-SPEED-STEEL BARS CONTAINING TITANIUM AND ALUMINUM
(See Table 2 for detailed chemical composition.)

proportions of cobalt, which, in individual cases were treated by, or according to the recommendations of, the manufacturer.

HOT-WORKING AND MACHINING PROPERTIES

An adequate idea of the working and machining characteristics of the steels listed in Table 2 can probably be obtained only under conditions approaching those of commercial production, but certain definite effects were observed in the working and machining of the experimental melts which deserve mention at this time.

Difficulties were encountered in forging two of the molybdenum steels, E31 and E29, Table 2. In both heats the ingots cracked badly and only small proportions were secured in final bar form. The tungsten-molybdenum steel (E31) was perhaps the worst in this respect as the ingot split under the first few light blows of the hammer. Possibly modifications in the forging practice employed would have been productive of better results, but it appeared that these molybdenum steels were more sensitive to working conditions than the ordinary types of high-speed steel.

So-called "sweating out" of the molybdenum—visible by the thick, bluish smoke arising from the steel—was observed only during forging (not in heat treatment), but examination of the forged bars of steel E29 indicated negligible losses of molybdenum.

[30] See footnote 20.

TABLE 11 MOLYBDENUM FOUND IN SUCCESSIVE LAYERS BENEATH THE SURFACE OF FORGED BARS OF STEEL E29[1]

Location of sample with respect to pickled and brushed surface	Molybdenum, per cent
Entire cross-section of bar	7.18
0 to 0.003 in. below surface	7.06
0.003 to 0.006 in. below surface	7.14
0.006 to 0.009 in. below surface	7.19
0.009 to 0.012 in. below surface	7.15
0.012 to 0.015 in. below surface	7.16
0.015 to 0.018 in. below surface	7.16

[1] Chemical composition given in Table 2.

Quite probably the smoke observed in forging was the volatilization of the molybdenum oxide already forming part of the scale.

One of the forged and annealed bars was first pickled in an ammoniacal citrate solution to loosen the scale, which was then carefully brushed or chipped from the underlying metal. Six successive cuts, each 0.003 in. deep, were then taken beneath the cleaned surface, and each of the six samples analyzed for molybdenum. Table 11 indicates negligible losses of molybdenum in the unoxidized metal unless the losses were concentrated in very shallow outer layers. However, this seems improbable, since, as pointed out by Bain,[31] molybdenum volatilizes very slowly, even in vacuo, and diffuses slowly in iron alloys, whereas the oxide of molybdenum is quite volatile. Rapid diffusion and rapid

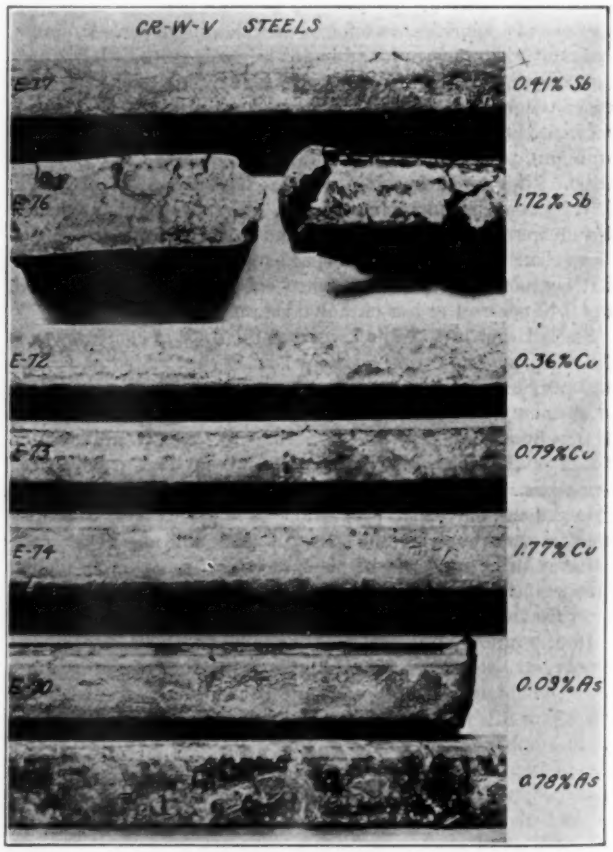


FIG. 18 APPEARANCE OF THE ROLLED HIGH-SPEED-STEEL BARS CONTAINING ARSENIC, ANTIMONY, OR COPPER
(See Table 2 for detailed chemical composition.)

volatilization would both be necessary for appreciable losses of metallic molybdenum at the unoxidized surfaces of the steel.

The steel containing 0.78 per cent aluminum did not have as good hot-working properties as steels without appreciable proportions of this element; see bad corner cracks (Fig. 17).

[31] E. C. Bain in discussion of paper referred to in footnote 27.

One of the steels containing titanium (E96) showed a high degree of hot shortness in rolling, although it seemed to forge in a satisfactory manner. This was probably not due either to the aluminum (0.08 per cent) or to high carbon (1.24 per cent) since a steel with equal carbon (E101) and steels with higher proportions of aluminum (0.38 per cent aluminum in steel E101 and 0.30 per cent aluminum in steel E87) had more satisfactory working properties. The splitting of the forged bar in rolling as shown in Fig. 17 may have been due to segregation. In this connection it should be noted that in this steel the recovery of titanium was only about 15 per cent of that added to the molten metal.

In general, the difficulties in hot working the different steels were more pronounced in rolling than in forging or pressing. The steels containing 1.7 per cent antimony or 1.8 per cent tin showed a high degree of hot shortness and could not be forged or rolled (see Fig. 18). The ingot of steel E48 containing 1.2 per cent tin "smoked" in forging like the high-molybdenum steels.

None of the other steels gave appreciable difficulties in forging, but several showed surface cracks, mostly at the corners, on rolling. Among these were the steels containing 0.4 per cent antimony, the steels with around 0.8 per cent or more of copper, the steel containing 0.8 per cent arsenic, and the steel containing 1.4 per cent carbon and 1.10 per cent tantalum.

All of the high-speed steels referred to in Table 2 could themselves be readily machined when in the annealed condition except the steel containing 1.8 per cent copper and the three steels containing about 3¾ per cent nickel and 0.6 to 0.7 per cent carbon. The steel with copper (E74) was machined with difficulty, but it was impossible to machine two of the nickel steels, E22 and E14, either in the cast or forged conditions even after prolonged annealing. Steel E130 was machined with difficulty, but with comparable proportions of nickel and lowered carbon content the machining properties were greatly improved. Steel E41, containing about 0.5 per cent carbon and 3½ per cent nickel, while not "soft," could be machined without great difficulty after annealing.

General Comments on the Lathe Tests

The steels referred to in Table 2 and the lathe-tool tests to be discussed were made at intervals over a long period of time on different test forgings, so that a direct comparison of all the tools is not practicable. This does not prevent determination of the effects of the added metals considered since each set of tests was considered to be complete in itself, and included one or more of the plain chromium-tungsten–vanadium high-speed steels as the basis for comparisons.

All tests were made at selected speeds, feeds, and depths of cut and the tool life determined. From six to twelve tools of each steel were tested for each of the selected cutting conditions. However, instead of reporting the average tool life, comparisons are made of the cutting speed permitting a tool life of 90 min. This was obtained from the average tool life by means of Equation [1] with $n = 1/10$ for tests made under shallow cuts and fine feeds ("trailer tool" tests) and with $n = 1/7$ for tests made with heavy cuts and coarse feeds (rough turning).[32]

The chromium-tungsten–vanadium steels used as the basis of comparisons in a majority of cases were experimental melts made in the same manner as the steels containing additions of the special elements. However, in some cases commercial high-speed steels were substituted for the experimental steels so that the performance of the different lathe tools might be viewed in the light of commercial products. The results recorded in Table 12 show that the experimental steels gave comparable performance to the commercial steels of like composition which were selected for comparisons under either shallow cuts and fine feeds or deep cuts and coarse feeds.

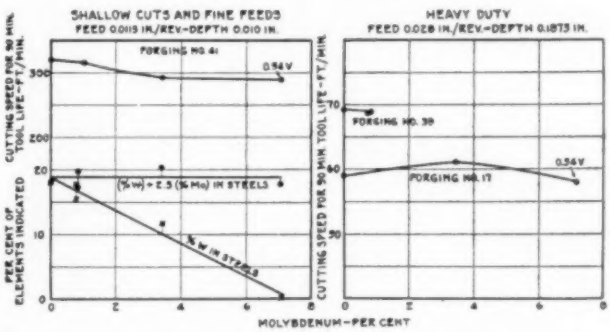


FIG. 19 EFFECT OF MOLYBDENUM ON THE CUTTING SPEED OF CHROMIUM-TUNGSTEN–VANADIUM-STEEL TOOLS WHEN TAKING SHALLOW CUTS AND WHEN TESTED UNDER HEAVY DUTY

(The molybdenum in these steels replaced a part or all of the tungsten, as indicated graphically on the left side of the chart and as explained in the text. Compositions of the tools and their heat treatment are given in Table 2; properties of the forgings are given in Table 3. All tests were made dry.)

Steels With Molybdenum

Many of the cobalt high-speed steels contain from 0.5 to 1 per cent of molybdenum, but ferrotungsten containing appreciable proportions of molybdenum has not always been considered to be desirable by American steel manufacturers.[33]

The four steels containing molybdenum (Table 2) may be said to fall into two classes, the one in which molybdenum was introduced as an impurity in the ferrotungsten, made from California scheelite ores, and the second in which molybdenum was used intentionally as a replacement of part or all of the tungsten.

Steels E109 and E107 were made with the idea of determining whether small amounts of molybdenum produced any appreciable effects upon the tool performance of the customary chromium-tungsten–vanadium high-speed steels. In steels E31 and E29 part or all of the tungsten was replaced by molybdenum in the

[32] The basis of the selected values for the exponent n in Equation [1] is discussed in Section V of this report and also in the reference of footnote 3.

[33] Private communications.

TABLE 12 COMPARISONS OF COMMERCIAL AND EXPERIMENTAL HIGH-SPEED TOOL STEELS IN LATHE TESTS

Steel no.[1]	Type of steel	Cutting conditions: Speed, ft. per min.	Feed, in. per rev.	Depth in.	Forging no.[2]	Number of tools tested	Average tool life, min.	Remarks
		Shallow Cuts and Fine Feeds						
L	Low W—high V	400	0.0154	0.005	40	10	47.1	Commercial steel
E97	Low W—high V	400	0.0154	0.005	40	10	48.8	Experimental melt
A	Low W—cobalt	380	0.0115	0.010	41	6	20.7	Commercial steel
E15	Low W—cobalt	380	0.0115	0.010	41	6	19.3	Experimental melt
		Deep Cuts and Coarse Feeds						
I	High W—low V	85	0.028	0.1875	17	8	7.4	Commercial steel
E21	High W—low V	85	0.028	0.1875	17	8	6.3	Experimental melt
A	Low W—cobalt	100	0.028	0.1875	42	6	13.8	Commercial steel
E15	Low W—cobalt	100	0.028	0.1875	42	6	14.1	Experimental melt

[1] See Table 2 for chemical compositions of the tools and their heat treatment; tool form given in Fig. 5.
[2] See Table 3 for chemical compositions and properties of the forgings cut.

TABLE 13 PERFORMANCE COMPARISONS UNDER SHALLOW CUTS OF CR-MO-V AND CR-W-V HIGH-SPEED-STEEL TOOLS

Steel no.[1]	Chemical composition, per cent C	Cr	W	V	Mo	Cutting conditions: Speed, ft. per min.	Feed, in. per rev.	Depth of cut, in.	Forging no.[1]	Avg. tool life, min.	Cutting speed for 90 min. tool life,[2] ft. per min.
E97	0.64	3.41	13.02	1.99	..	380	0.0115	0.010	41	16.4	320
E97	0.71	4.74	..	0.54	7.07	380	0.0115	0.010	41	6.0	290
E29	0.64	3.41	13.02	1.99	..	400	0.0115	0.005	41	14.6	333
E29	0.71	4.74	...	0.54	7.07	400	0.0115	0.005	41	13.8	332

[1] See Tables 2 and 3, respectively, for details of tool-steel treatments and properties of forging No. 41; tool form shown in Fig. 5(*b*).
[2] Computed by means of Equation [1] of the text with $n = 1/10$.

TABLE 14 ROUGHING-LATHE-TOOL PERFORMANCE OF HIGH-SPEED STEELS WITH AND WITHOUT MOLYBDENUM REPORTED BY SOME EARLIER INVESTIGATORS

Chemical composition, per cent C	Cr	W	V	Mo	W + 2½(Mo) per cent	Relative tool performance	Lb. metal removed in speed-increment tests	Source of data
0.79	4.27	23.90	0.69	..	23.90	1.35	...	Hohage and Grutzner; *Stahl u. Eisen*, July, 1925, p. 1126
0.79	3.18	12.40	0.52	3.98	22.35	1.00	...	
0.63	3.14	18.70	0.49	..	18.70	1.02	...	
0.55	2.62	15.93	1.16	..	15.93	..	110	Arnold and Ibbotson; *Jl. Iron & Steel Inst.*, vol. 99 (1919), p. 407
0.76	2.82	12.12	1.28	2.06	17.27	..	96	
0.75	2.79	...	1.29	5.79	14.47	..	112	

approximate ratio of 1 part molybdenum for each 2½ parts of tungsten. This ratio represents approximately equivalent effects as determined in lathe-tool tests by Arnold and Ibbotson.[24]

While not strictly accurate, all four of the steels with molybdenum may be considered to be modifications of the customary high-tungsten–low-vanadium high-speed steel in which 1 part of molybdenum has replaced approximately 2½ parts of tungsten, and it is on this basis that the results of the lathe tests are summarized in Fig. 19.

It would appear from Fig. 19 that molybdenum may be substituted for part or all of the tungsten without radically changing the lathe-tool performance under shallow cuts and fine feeds or under heavy duty. If the results in Fig. 19 show any definite trends, they are that molybdenum is somewhat disadvantageous from the standpoint of shallow cuts but may improve the steels for heavy duty.

More definite conclusions cannot be drawn since steels E31 and E29 are respectively low in carbon and in vanadium, and the importance of these variations when taking shallow cuts is not known at this time.

The performance of the molybdenum steel E29 (without tungsten) was somewhat irregular under shallow cuts, as is shown in Table 13. The cutting speed in one set of tests was almost identical with that of the tungsten steel E97, but in another set of tests made with a deeper cut was somewhat lower.

The rough-turning tests did not establish superiority or inferiority of the high-speed-steel tools containing molybdenum, and in this respect the results in Fig. 19 are consistent with those obtained by earlier investigators who, in some cases, found that the steels with molybdenum gave better performance than the tungsten steels while in other cases this order was reversed. Detailed comparisons of the results of some previous investigations are given in Table 14.

As far as can be judged from the described tests, the replacement of tungsten by molybdenum is not a substitution which should be advocated for lathe tools, but in case of a depleted tungsten supply molybdenum would be very useful in producing steels with at least the same general order of performance as is obtained with the present tungsten high-speed steels.

The high-molybdenum steels such as E29 have one advantage over the tungsten steels for roughing tools in that their hardness

[24] J. O. Arnold and F. Ibbotson, "The Molecular Constituents of High-Speed Tool Steels and Their Correlations With Lathe Efficiencies," *Jl. Iron & Steel Inst.*, vol. 99 (1919), no. 1, p. 407.

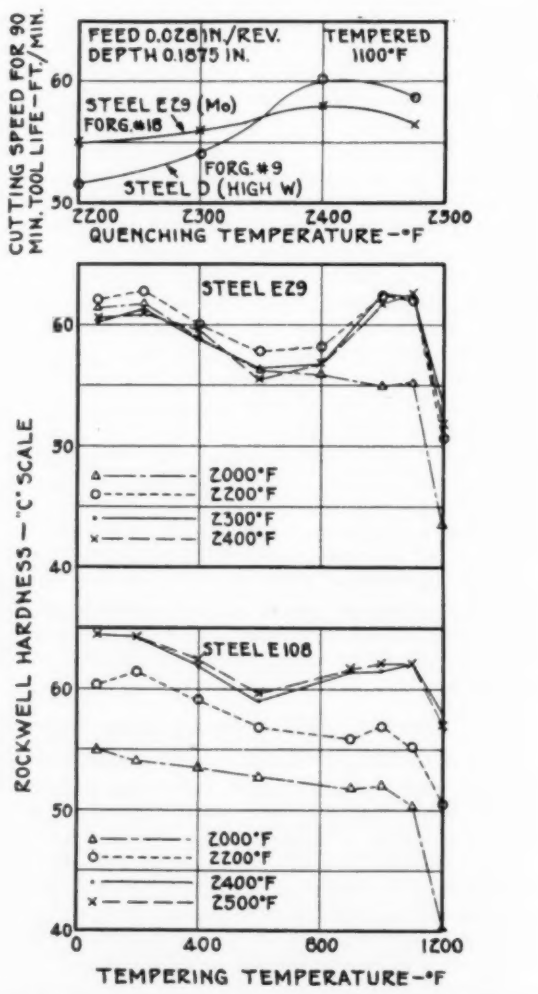


FIG. 20 EFFECT OF HEAT TREATMENT ON THE CUTTING SPEED AND HARDNESS OF SOME OF THE HIGH-SPEED STEELS CONTAINING MOLYBDENUM

(Composition of the tools and their heat treatments are given in Table 2; properties of the forgings are given in Table 3. All lathe tests were made dry. Quenching temperatures are shown in the body of the chart. The cutting speed of steel D containing no molybdenum is given for comparison with the molybdenum steel E29.)

and performance is not so largely affected by variations in the hardening temperatures as is shown in Fig. 20. When hardened from low temperatures around 2200 deg. fahr., the high-molybdenum steel actually showed better performance than the customary tungsten steels similarly treated. On the other hand, the hardness of the tungsten steels containing 1 per cent or less of molybdenum was the same as that of corresponding steels without molybdenum when subjected to the same heat treatments.

Up to the present time it has not been practicable to expect uniformly good performance from high-molybdenum high-speed-

steel tools, but more extended experience with such steels would probably result in the development of a technique in manufacture and handling which would result in a more satisfactorily uniform performance.

Steels With Cobalt

Cobalt has been an important element in the so-called tungsten-less alloys for high-speed cutting tools, but the steels considered here are the customary chromium-tungsten-vanadium steels modified only by additions of cobalt. In the commercial steels of this type, from 2.5 to 5 per cent of cobalt has usually been added, but more recently steels with much higher proportions of cobalt have been placed on the American market. Some of these also contain molybdenum in proportions up to about 1 per cent, but since the results already described showed that 1 per cent or less of molybdenum had no appreciable influence on the cutting speeds of the customary chromium-tungsten-vanadium steels, either with shallow cuts or under heavy duty, the presence of 0.6 and 0.9 per cent molybdenum, in steels CC and Y, respectively, Table 2, may be disregarded.

Several advantages are known to result from the addition of cobalt to the customary high-speed-steel compositions. Steels with around 5 per cent cobalt can be hardened from somewhat higher temperatures than would be safe for the corresponding steels without cobalt,[35,36] and under such conditions of treatment will, on the average, give better performance under very heavy duty where the deep cuts and coarse feeds produce high frictional temperatures.

Another advantage of the cobalt steels reported by European investigators[37] is that their performance is not so largely dependent upon the hardening temperature as is the case in corresponding steels without cobalt, and with low hardening temperatures, say, around 2300 deg. fahr., higher hardness and better performance can be expected. However, the cobalt steels are reported to acquire a soft skin on hardening,[38] with the result that they have not been widely used in form cutters or other tools which must be heat treated in finished form.

The high-cobalt steels, similar to CC and Y, Table 2, have been reported to give excellent performance in cutting hard metals; it is claimed[39] they have also made practicable the commercial machining of 14 per cent manganese steels, but the best performance is obtained only when the highest possible hardening temperatures are used.

Under shallow cuts and fine feeds, higher cutting speeds were shown by the steels with cobalt than by those without, but 8 to 12 per cent of cobalt was no more effective than 5 per cent (Fig. 21). Furthermore, the benefits derived from the cobalt were not large, amounting to 10 to 25 ft. per min. for cutting speeds of the order of 325 ft. per min.

Similar effects were found in the heavy-duty tests as is shown in Fig. 21. With the exception of steel CC, Table 2, the cutting speed increased with the proportion of cobalt, but the increase between 3.5 and 12 per cent was not nearly as large as that between 0 and 3.5 per cent. With 3.5 per cent cobalt there was a somewhat larger percentage gain in the heavy-duty tests than in the tests under shallow cuts and fine feeds.

Superior performance of the steel with 3.5 per cent cobalt was probably due to the fact that it was hardened from a temperature 50 to 75 deg. fahr. higher than that used in hardening the 8 per cent and 12 per cent cobalt steels and the steel without cobalt. Results reported by Oertel and Polzguter,[40] which have been included in Fig. 21, indicate that cobalt additions around 3 per cent do not result in greatly increased cutting speeds when the steels are all hardened from the same temperatures.

There is little doubt that cobalt by itself tends to increase the cutting speed, but the maximum benefits are derived only with modified heat treatments. The results given in Fig. 21 show further that cobalt additions are of somewhat greater benefit for heavy duty than for tools used with shallow cuts and fine feeds. But in rough-turning nickel steels such as were used in the described experiments, increase in cobalt above about 5 per cent did not produce improvements commensurate with those resulting from additions of 3.5 to 5 per cent cobalt and high hardening temperatures.

Steels With Arsenic, Antimony, Copper, or Tin

As a general rule, little attention is paid by consumers to the presence of copper, tin, arsenic, or antimony in commercial high-speed tool steels, although it is known that all of these elements

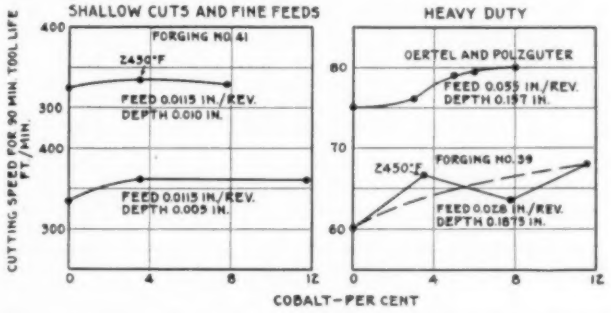


Fig. 21 Effect of Cobalt on the Cutting Speed of High-Speed-Steel Tools When Taking Shallow Cuts and Under Heavy Duty

(Compositions of the tools are given in Table 2; properties of the forgings are given in Table 3. Unless otherwise indicated the tools were oil quenched from 2375 to 2400 deg. fahr. and tempered at 1050 to 1100 deg. fahr. All tests were made dry. The source of the data credited to Oertel and Polzguter is given in footnote 24 of the text.)

will be found occasionally, and some of them frequently, in the American products. Some may be introduced from scrap which forms part of the original charge, or, as is sometimes the case with tin and arsenic, small proportions may be present as impurities in the ferroalloys used in manufacture. In any case, arsenic, antimony, copper, and tin are generally believed to exert harmful effects upon high-speed tool steels.

According to Sandberg,[41] copper, tin, arsenic, bismuth, and antimony are ordinarily present in small amounts in high-speed steels, but have no ill effects unless they are present, individually, in excess of 0.02 per cent. McKenna[42] states that the detrimental effects of tin, copper, and arsenic are not generally realized by the trade, and that small quantities of these impurities are exceedingly harmful. The character of the data upon which these statements are based is not known, and technical literature does not contain information on the magnitude of the effects produced by different proportions of the metals in question or whether they are equally deleterious for all classes of service. The need for further information is shown by inquiries which have been received by the Bureau from time to time from consumers and producers and by the fact that the American Society

[35] See footnote 20.

[36] F. Repatz, "Die Leistung von Schnellstahlmessern und ihre Prüfung," *Stahl u. Eisen*, vol. 49 (1926), p. 1109.

[37] See footnote 25.

[38] See footnote 28.

[39] A. S. Martin, "Machining Manganese Steel on a Commercial Basis," *Iron Trade Review*, vol. 82 (1928), p. 564.

[40] See footnote 24.

[41] R. M. Sandberg, "Progress in Hardening High-Speed Steel," *Fuels and Furnaces* (F. C. Andresen and Associates, Pittsburgh, Pa.), vol. 6, no. 1, January, 1928, p. 53.

[42] R. C. McKenna, "Practical Information Concerning High-Speed Steel," *Am. Mach.*, vol. 51 (1919), p. 989.

for Testing Materials has a committee appointed to study the effects of tin and arsenic in high-speed tool steels.

A large part of the results here described were discussed in a preliminary report,[42] but since a much broader background is now available for the interpretation of the tool tests under shallow cuts and fine feeds, reference will again be made briefly to the effects of copper, tin, arsenic, and antimony upon the performance of high-speed-steel turning tools.

The results of tests under shallow cuts and fine feeds and also those under heavy duty are grouped in Fig. 22, and show that the influence of the different elements considered was a function of the conditions to which the tools were subjected.

With shallow cuts, each of the four elements, copper, tin, arsenic, and antimony, adversely affected the tool performance, and in each case the magnitude of the decrease in tool life or the

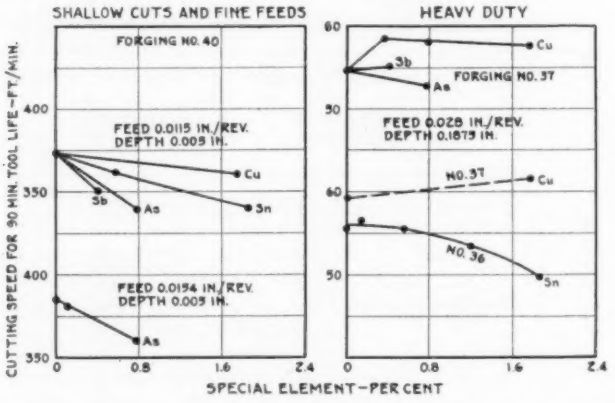


FIG. 22 EFFECTS OF ARSENIC, ANTIMONY, COPPER, AND TIN ON THE CUTTING SPEED OF HIGH-SPEED-STEEL TOOLS UNDER SHALLOW CUTS AND UNDER HEAVY DUTY

(Compositions of the tools and their heat treatment are given in Table 2; properties of the forgings are given in Table 3. All tests were made dry.)

cutting speed became greater as the proportion of the impurity was increased. Copper was the least harmful; next in order came tin, while arsenic and antimony were the most objectionable.

The effects of the several elements upon the performance of roughing tools did not necessarily correspond to those observed with shallow cuts. The arsenic addition lowered the cutting speed, but the addition of 0.4 per cent antimony or 0.5 per cent or less of tin had no measurable effect. Higher proportions of tin lowered the cutting speeds, but the high-speed steels containing copper showed slightly better performance than the corresponding steels without copper. This effect was confirmed in two independent sets of tests as is shown in Fig. 22.

The described results seem to justify the conclusions that copper has the least harmful effect of the four metals here considered upon the cutting speeds of high-speed-steel turning tools; and that small proportions of tin, below about 0.1 per cent, do not seriously affect the cutting speeds, but that arsenic and antimony should be kept out of high-speed tool steels to be used under varied conditions of service.

In general, the presence of small proportions of these different elements is much less important for tools to be used only in rough turning than when shallow cuts are considered. This is perhaps to be expected, since any tendency to promote crumbling of the cutting edge, which would be observed with shallow cuts when the frictional temperatures are low, would probably be masked by the softening of the steel at the high operating temperatures encountered in rough turning.

[42] H. J. French and T. G. Digges, "Effects of Antimony, Arsenic, Copper, and Tin in High-Speed Tool Steel," Trans. Am. Soc. Steel Treating, vol. 13 (1928), p. 919.

In addition to lathe-tool tests, Rockwell hardness tests were made on samples quenched and tempered in various ways, and with few exceptions the hardness of the steels containing the different impurities was practically the same as that of the steels without these impurities similarly treated. The addition of 0.15 per cent tin increased the hardness of the steel as oil quenched from 2000 deg. fahr.; when the proportion of tin was raised to 0.57 per cent, there was an additional increase in the hardness, but with further increase in tin the hardness decreased slightly.

The additions of antimony, arsenic, copper, or tin produced no outstanding changes in the structures of the high-speed-steel tools, although there was a tendency for increase in grain size with increase in copper content and a decrease in grain size as the proportions of antimony, arsenic, or tin were increased. Typical structures are shown in a preliminary report referred to in footnote 43 of the text.

STEELS WITH ALUMINUM

The principal reason for considering the effects of aluminum upon the high-speed-steel tools was the presence of this element in the ferrotitanium available and its consequent introduction into the steels containing titanium. Without knowing something of the magnitude of the effects of the aluminum, the trend of the effects produced by the titanium could not be established. However, aluminum is widely used as a corrective agent in steel-making practice. While ordinarily avoided in the manufacture of high-speed tool steels, aluminum is sometimes added in the ladles or molds and its influence upon the performance of high-speed-steel cutting tools becomes important.

As far as is known, the effect of aluminum upon high-speed-steel tools has not been made the subject of investigations which have reached the stage of publication, but generally useful information has been gathered in other fields. Small additions of aluminum to molten iron alloys will react with any iron oxide present to form alumina, a part of which may be eliminated under suitable conditions. With larger additions of aluminum the same reactions can take place, but the larger part of the aluminum is dissolved in the steel as aluminum.

According to Guillet,[44] the presence of aluminum in iron-carbon alloys "has the effect of preventing the pearlite from assuming its ordinary forms; it is, in a manner, contorted, and forms little nodules which are the more easily colored by picric acid, and the more closely resemble troostite, in proportion as the percentage of aluminum increases. With a very high percentage of aluminum it is even possible to have free cementite formed in a hypo-eutectoid steel.

"Quenching transforms only the nodules of the preexisting pearlite, giving place to martensite, generally encircled around its edges by troostite. The result is always the same, no matter what the temperature of quenching. It must therefore be recognized that the iron-aluminum solution is incapable of dissolving carbon.

"From the mechanical point of view quenching has no effect except when the pearlite exhibits its ordinary structure, that is to say, so long as the aluminum is below 3 per cent."

Aluminum was found to increase the tensile strength and decrease the elongation and reduction of area, slowly at first but rapidly when the aluminum was raised above 3 or 4 per cent; the brittleness also increased rapidly.

The effects produced in the high-speed steels by aluminum were similar in some respects to those described by Guillet for carbon steels, but were observed with smaller additions of aluminum. As is shown in Figs. 23 and 24, the hardness of the steels containing aluminum decreased, after either quenching or

[44] L. Guillet, "Quaternary Steels," *Jl. Iron & Steel Inst.*, 1906, no. 2, p. 1.

quenching followed by tempering, as the proportion of aluminum was raised from practically zero to 0.8 per cent. However, the numerical values of the hardness obtained were quite largely dependent upon the quenching temperature. In effect, the entire set of hardness curves (Fig. 23) was shifted to lower values of hardness as the proportion of aluminum was increased.

Aluminum also adversely affected the performance of the high-speed-steel tools both with shallow cuts and under heavy duty as is shown in Fig. 25. In fact, aluminum was one of the few metals considered which in small proportions (around 0.3 per cent) produced a measurable decrease in the cutting speeds in rough turning. This decrease became greater as the proportions of the aluminum were increased, and with 0.8 per cent the drop in the cutting speed was greater than that produced by equal proportions of any of the other elements considered.

Deleterious effects were observed with shallow cuts and fine feeds, but in this case the effects of the aluminum were about on a par with those of arsenic and antimony, and more marked than those of either tin or copper.

The reasons for decrease in the hardness and the tool performance with increase in the aluminum have not been established, but the structures of the steels throw some light on this subject.

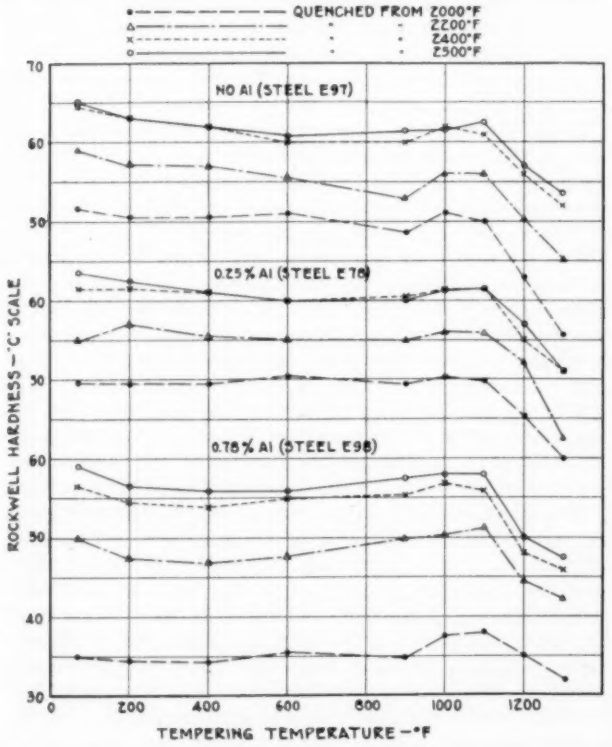


FIG. 23 HARDNESS OF HIGH-SPEED STEELS CONTAINING DIFFERENT PROPORTIONS OF ALUMINUM WHEN SUBJECTED TO DIFFERENT HEAT TREATMENTS
(Compositions of the steels are given in Table 2.)

The structure of one of the quenched and untempered high-speed-steel tools containing about 0.8 per cent aluminum was perhaps the most illuminating since it showed characteristics somewhat similar to those described by Guillet for carbon steels. As is shown in Fig. 26(*c*), a large number of undissolved particles were found at the austenite grain boundaries and the outer areas of the zones of concentration of these undissolved constituents were encircled by more darkly etched areas perhaps representing a structure comparable to troostite.

Such a large number of undissolved aggregates are not ordinarily found in the customary high-speed steels quenched from comparable temperatures [Fig. 26(*a*)] and probably represent a decreased dissolving power of the austenite (matrix) for one or more of the elements, carbon, chromium, tungsten, and vanadium

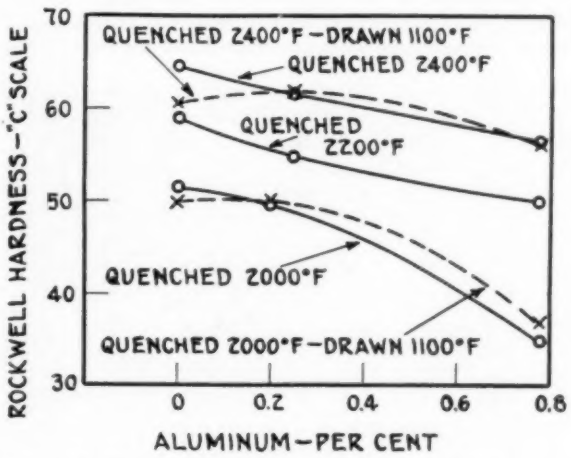


FIG. 24 EFFECT OF ALUMINUM ON THE HARDNESS OF QUENCHED AND TEMPERED HIGH-SPEED STEEL
(Compositions of the steels are given in Table 2.)

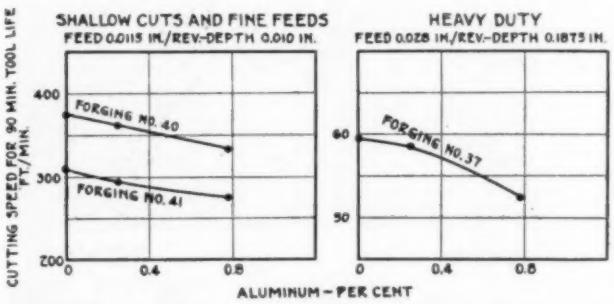


FIG. 25 EFFECT OF ALUMINUM ON THE CUTTING SPEED OF HIGH-SPEED-STEEL TOOLS UNDER SHALLOW CUTS AND UNDER HEAVY DUTY
(Compositions of the tools and their heat treatment are given in Table 2; properties of the forgings are given in Table 3. All tests were made dry.)

which constitute the key elements in the steels under consideration.

In other words, the 0.8 per cent aluminum has decreased the solubility in the austenite of one or more of the elements mentioned, and through the resultant precipitation has lowered the hardness and other useful properties of the steel. Along with this precipitation is evidence of the formation of low-melting-point eutectics [see arrow, Fig. 26(*c*)] which are only evident in the customary high-speed steels as cast or when overheated. Such partial melting is an added source of danger in high-speed-steel tools, and probably contributed in a measurable degree to the poor performance described.

The exact nature of the compounds and the low-melting eutectics has not been determined, but the observed structures, hardness, tool performance, and poor hot-working properties previously described clearly show the importance of guarding against the introduction of more than very small proportions of aluminum in high-speed tool steels.

STEELS WITH TITANIUM

So far titanium has not shown much promise as an alloying element in steels and is now mainly used as one of a number of corrective agents (scavengers) in steel making, and in this latter

field it seems to combine most readily with oxygen and nitrogen. The present situation regarding the applications and effects of titanium in steels is about as described by Gillett and Mack[45] as follows:

"The alloying effect of titanium seems to be negligible, its only use being as a scavenger to remove oxygen and perhaps nitrogen. It seems to reduce segregation of carbon and of impurities. Some

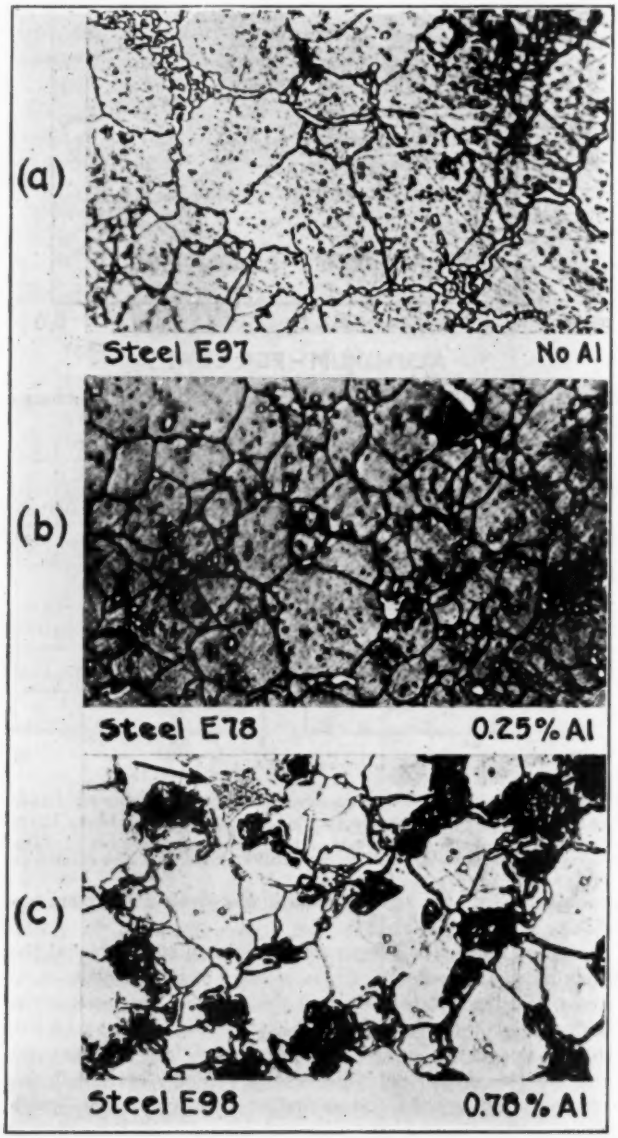


FIG. 26 STRUCTURES OF HARDENED HIGH-SPEED STEELS CONTAINING DIFFERENT PROPORTIONS OF ALUMINUM ×750
(Samples oil quenched from 2350 deg. fahr., not tempered. Etched with 2 per cent HNO_3 in alcohol.)

of the data cited by the advocates of titanium[46,47] to show its value as a scavenger lie well within the range of results obtained without it and the proof of its usefulness is seldom clear-cut.

A thorough study[48] of the deoxidation of rail steel by titanium and by silicon has been made by the Bureau of Standards. This shows that the action of titanium in restraining segregation is definitely shown only in the top of the ingot, that the average mechanical properties of the steel are not noticeably altered by titanium, and that the claim that the oxidation products of titanium do not remain in the steel is not in accord with the facts.

"Stoughton[49] believes that titanium causes occluded oxidized materials which would cause inclusions to be more readily separated from the melt, and Giolitti[50] mentions the use of titanium and vanadium as having specific action in developing fine grain on heat treatment. Titanium probably serves a useful purpose as a scavenger, but it has no place in a list of true alloying elements."

According to recent studies by Tamaru,[51] titanium up to 4 per cent is in solid solution in the ferrite of carbon steels; it lowers the solubility of carbon in the austenite and accelerates graphitization. As the titanium in the steel was increased the carbon content of the eutectic decreased.

True alloying of any appreciable amounts of titanium in steels is not readily accomplished. Ferrocarbon titanium ordinarily employed in titanium-treated steels does not serve satisfactorily for such a purpose, under ordinary manufacturing conditions, since the titanium carbides present in the ferroalloy are not readily dissolved in the steel. Even with so-called carbon-free ferrotitanium, favorable conditions were found to be necessary for a reasonably good recovery of the added titanium.

In the five high-speed steels containing titanium which are listed in Table 2, the titanium was added to, and did not replace any portion of, the elements ordinarily present. Three of these steels contained about the customary proportions of carbon, while two others were much higher in carbon content.

With 0.6 to 0.8 per cent carbon and 0.4 per cent or less of titanium the hardness of the steels increased generally with increase in the quenching temperature in much the same manner as corresponding steels without titanium, but the effect of quenching temperature was more marked in the steel containing 0.4 per cent titanium than in that with 0.24 per cent (Fig. 27).

With any one quenching temperature the hardness of the untempered samples decreased as the titanium was increased, and with 1.85 per cent titanium the steel would not harden when quenched from any temperature between 2000 and 2500 deg. fahr.

When the carbon was raised from around 0.7 per cent to 1.2 per cent and the titanium kept at around 1.8 per cent, the steel again hardened upon quenching, the hardness being dependent upon the quenching temperature used. However, with comparable carbon (1.2 per cent) and less titanium (0.29 per cent) the hardness on quenching decreased with increase in the quenching temperature, probably indicating the retention of more austenite. When first quenched from 2000 deg. fahr., samples of this latter steel showed no rehardening on tempering (Fig. 27), as did the samples quenched from 2300 to 2500 deg. fahr.

These results are all shown graphically in Fig. 27 and indicate that the hardness of the quenched steels was not solely a function of the proportion of titanium but depended upon the relative amounts of titanium and carbon present.

The performance of the high-speed-steel tools containing ti-

[45] H. W. Gillet and E. L. Mack, "Molybdenum, Cerium, and Related Alloy Steels," Chemical Catalog Co., Inc., New York, 1925.
[46] Titanium Alloy Mfg. Co., "Titanium, Its Effects on Steel," Booklet, 1919.
[47] Titanium Alloy Mfg. Co., "Ferro-Carbon Titanium in Steel Making," Booklet, 1916.
[48] G. K. Burgess and G. W. Quick, "A Comparison of the Deoxidation Effects of Titanium and Silicon on the Properties of Rail Steel," Bureau of Standards Tech. Paper no. 241, 1923.
[49] B. Stoughton, "The Metallurgy of Iron and Steel," McGraw-Hill Book Co., Inc., 1923, p. 206.
[50] F. Giolitti, "Steel Castings of High Strength and Toughness," *Chem. & Met. Eng.*, vol. 24 (1921), p. 161.
[51] K. Tamaru, "On the Equilibrium Diagram of the System Iron–Carbon–Titanium," Science Reports of the Tohoku Imp. Univ., Series I, 15, no. 1 (March, 1925), p. 25.

TABLE 15 EFFECTS OF TITANIUM IN HIGH-SPEED TOOL STEELS ESTIMATED FROM DATA GIVEN IN FIGS. 25 AND 28

Steel no.	Partial chemical composition per cent[1] C	Ti	Al	—Reduction in cutting speed[2] produced by— Ti + Al (from Fig. 28) shallow cuts	heavy duty	Equivalent Al (from Fig. 25) shallow cuts	heavy duty	Ti (Ti + Al) − Al = Ti shallow cuts	heavy duty
E51	0.80	0.24	..	6	−2	0	..	6	−2
E99	0.59	0.41	0.06	27	10	3	0.5	24	9.5
E87[3]	0.69	1.85	0.30	310	60	15	1.5	295	58.5
E96	1.24	0.29	0.08	63	8	4	0.5	59	7.5
E101	1.20	1.80	0.38	18	4	20	2	−2	2

[1] For complete composition and heat treatment of the tools, see Table 2.
[2] For 90-min. tool life under the conditions indicated in Figs. 25 and 28.
[3] Would not cut.

tanium and the customary proportions of carbon was disappointing. As shown in Fig. 28, the cutting speeds decreased both with shallow cuts and under heavy duty as the titanium was increased. The steel with about 0.7 per cent carbon and 1.8 per cent titanium which would not harden also failed to cut at the speeds used in the experiments. Tests at lower speeds might

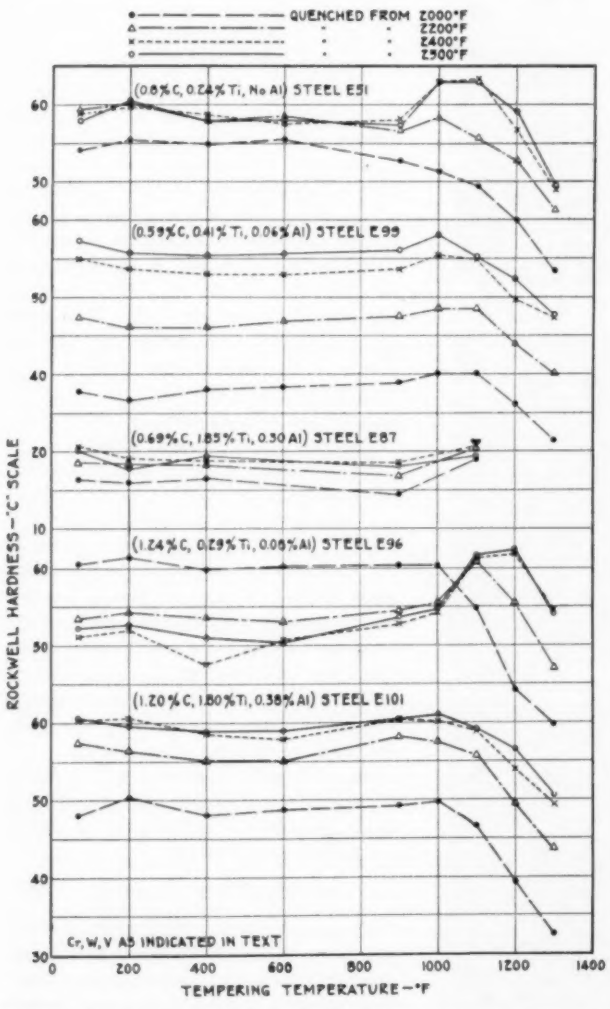


FIG. 27 HARDNESS OF HIGH-SPEED STEELS CONTAINING DIFFERENT PROPORTIONS OF TITANIUM (AND ALUMINUM) WHEN SUBJECTED TO DIFFERENT HEAT TREATMENTS

(Complete chemical compositions are reported in Table 2.)

have resulted in a measurable duration of cut, but for all practical purposes the steel referred to did not have cutting properties comparable to high-speed tool steels.

When the carbon in the steels was raised to 1.2 per cent, increase in titanium from about 0.3 per cent to 1.8 per cent resulted in improved performance both under shallow cuts and under heavy duty. However, the performance of tools of steel E96 may not be characteristic of the reported composition for reasons later explained, but in no case did the steels containing titanium give as good performance as the high-speed steels of customary composition without titanium.

It should be noted that increase in the proportions of titanium resulted in an increase in the proportions of aluminum in the high-speed steels. Aluminum has already been shown to have a highly

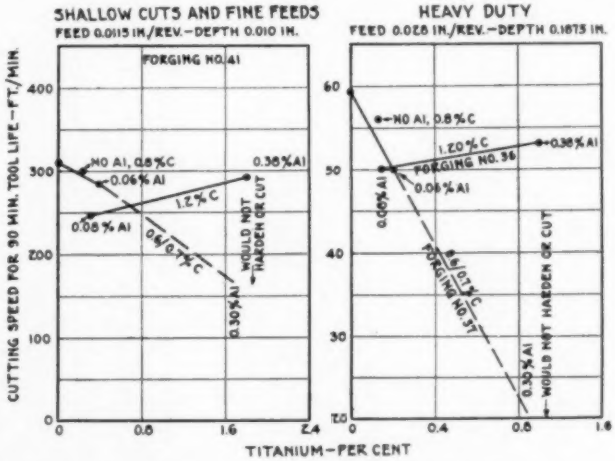


FIG. 28 EFFECT OF TITANIUM (PLUS ALUMINUM) ON THE CUTTING SPEED OF HIGH-SPEED-STEEL TOOLS UNDER SHALLOW CUTS AND UNDER HEAVY DUTY

(Compositions of the tools and their heat treatment are given in Table 2, properties of the forgings are given in Table 3. All tests were made dry.)

deleterious effect upon the performance of high-speed-steel tools, and therefore the changes in the cutting speeds shown in Fig. 28 cannot be ascribed entirely to titanium.

The reductions in the cutting speeds produced by the different proportions of aluminum found in the titanium high-speed steels can be estimated from data given in Fig. 25, and if these reductions in the cutting speed are subtracted from those produced by titanium plus aluminum given in Fig. 28, the effects of titanium alone can be estimated. These calculations are incorporated in Table 15, and show that appreciable proportions of titanium exerted a highly deleterious effect upon the cutting speeds, both with shallow cuts and under heavy duty except in the case of the two high-carbon steels.

While the effects of titanium alone, as given in Table 15, are smaller than those shown in Fig. 28, the estimated corrections for aluminum did not change the general trends shown in Fig. 28.

All of the titanium steels contained characteristic pink or orange-colored titanium inclusions, probably nitrides or cyanonitrides [Figs. 29 (*b*), 29 (*c*), 30 (*b*), 31 (*b*), and 31 (*c*)]. The structure shown in Fig. 30 (*a*) for steel ES7, which could not be hardened appreciably by heat treatment, is probably a solid solution of alpha iron, titanium, and aluminum plus a large number of carbides, tungstides, titanium inclusions, and possibly other undissolved particles.

As the titanium content of the steels was increased, the number of undissolved particles also increased as is shown in Figs. 29(*c*), 29(*f*), and 30(*c*), for the steels containing 0.6 to 0.8 per cent carbon and in Figs. 31(*c*) and 31(*f*) for the steels containing 1.2 per cent carbon. The darkened patches between the grains in the etched sample of steel E101, shown in Fig. 31(*d*), are probably due to the aluminum present and resemble features shown in

Fig. 26 (*c*) for high-speed steel containing about 0.8 per cent aluminum without titanium.

The structures shown in Figs. 29, 30, and 31 indicate that titanium decreases the dissolving capacity of the austenite for the elements which ordinarily are responsible for the characteristic properties of high-speed steels through their solution at high hardening temperatures.

However, titanium is known to form carbides very readily, and in the presence of varying amounts of carbon different effects may be produced. In the presence of high carbon the titanium will probably first form carbides, and any titanium remaining may then go directly into solution in the iron. This of course assumes that there is an excess of titanium available. In the high-speed steel containing 1.2 per cent carbon and 1.8 per cent titanium (E101), the high carbon restored the ability of the steel to harden upon quenching and gave a tool performance nearly equal to that of high-speed steels of customary composition. However, these benefits were probably not derived from any useful alloying effects of titanium but probably were produced by putting the titanium in a less harmful condition (carbides instead of solution in the iron), so that the chromium, tungsten, and vanadium could act in their normal manner.

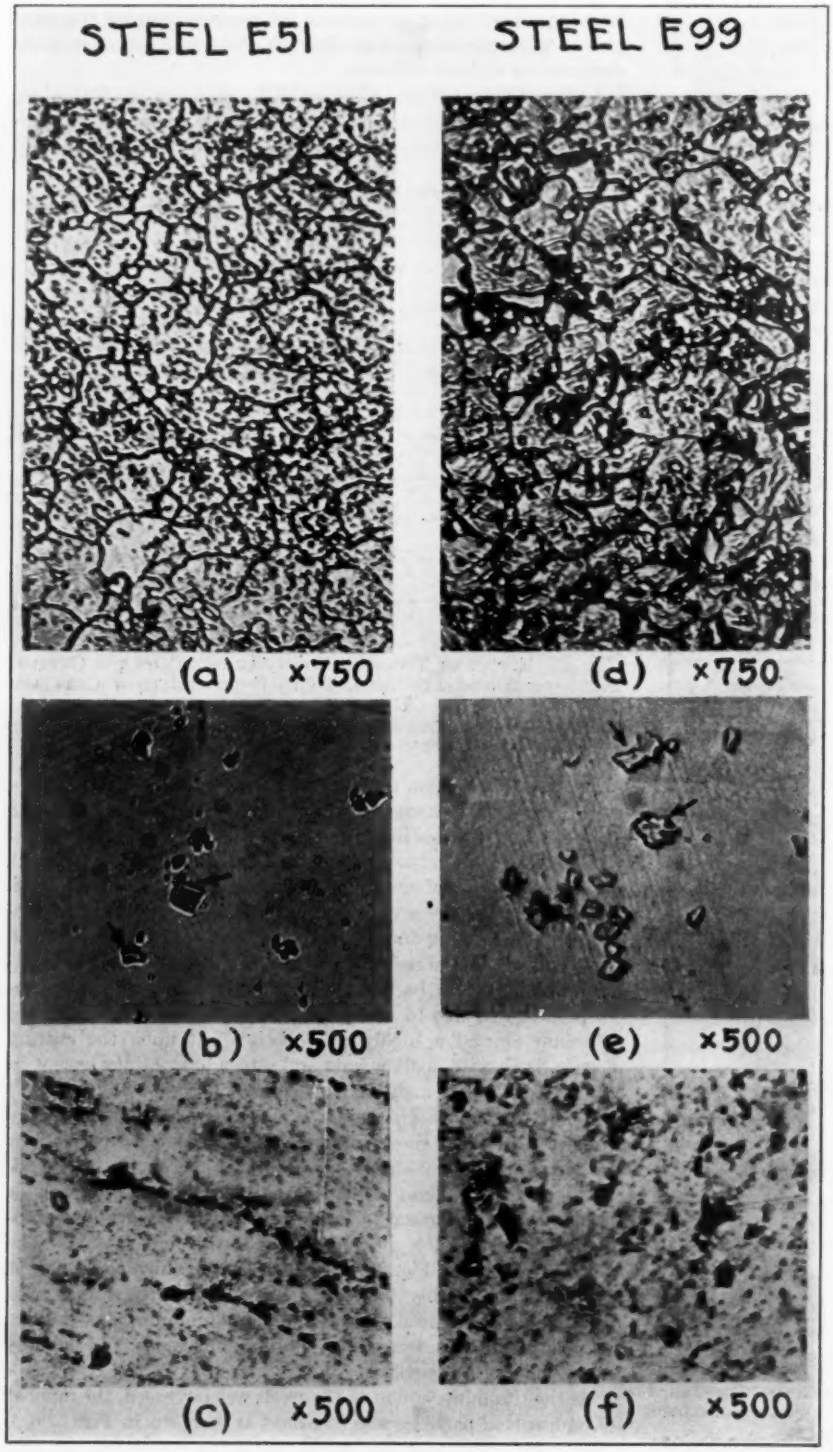


FIG. 29 STRUCTURES OF HARDENED HIGH-SPEED STEELS CONTAINING DIFFERENT PROPORTIONS OF TITANIUM (AND ALUMINUM)

(Compositions of the steels are given in Table 2; *a* and *d* etched with 5 per cent HNO_3 in alcohol; *b* and *e* unetched; *c* and *f* etched in boiling solution of $KMnO_4$ (4 grams), NaOH (4 grams) in 100 cc. H_2O. Samples first oil quenched from 2350 deg. fahr.)

The low cutting speed of the high-carbon, high-speed-steel tools containing only 0.29 per cent titanium cannot be explained at this time, but was probably due either to the high carbon in the absence of appreciable amounts of titanium or to peculiarities of the particular heat from which the tools were prepared. The recovery of titanium in this steel was low, its working properties were poor (Fig. 17), and, as has already been pointed out, it probably had areas of segregation.

Titanium may therefore be considered to be an undesirable addition to the customary high-speed-steel compositions since it probably decreases the dissolving power of the austenite for these compounds which must be brought into solution to produce the properties characteristic of ordinary high-speed steels. Its interference is lessened probably through the formation of less harmful carbides (instead of solution as titanium in the austenite), by increasing the carbon content of the steel. The amount of carbon required will probably vary with the titanium content, and was in the neighborhood of 1.2 per cent carbon for 1.8 per cent titanium.

STEELS WITH TANTALUM

During the year 1924, while a study was being made of the chemical composition of heavy-duty lathe tools, rumors were received that promising results were being obtained in England with high-speed steels containing tantalum. While no details were available, and no performance records could be obtained at that time, a number of experimental steels were made containing different proportions of tantalum and tested in comparison with high-

speed steels of customary composition. The tests were made with deep cuts and coarse feeds, but more recently the same steels were tested under shallow cuts and fine feeds, and a summary of all of the results is now given for the first time.

A report of the preliminary experiments was made in 1925,[52] and discussion of the results brought to light some further information on tantalum in tool steels. One British metallurgist reported[53] that he had made a series of steels presumably with 0.6 per cent carbon, some chromium, and from 1 to 6 per cent tantalum. The steel with 6 per cent tantalum showed properties somewhat similar to the "red hardness" of ordinary high-speed tool steels. In further work, a steel containing about 6 per cent tungsten and 6 per cent tantalum was said to have had about 75 per cent "cutting efficiency" in comparison with the usual tungsten steels.

J. P. Gill[54] reported that during the years 1920–1921, the firm with which he was associated had spent some time in a study of tantalum in high-speed tool steels. He stated that "this company probably made up as many as one hundred different composition high-speed steels containing tantalum, tungsten, chromium, vanadium, and cobalt. Some of the heats made were as large as 7000 lb. Lathe tests were run, many physical tests were made, and it was found that several of the steels compared favorably with some of the regular high-speed steels in commercial use today, but these steels were no better than the same steels without tantalum. We did not find any steels that were better than the regular high-speed steels. Many things were learned in regard to the use of tantalum. The manner of introducing the tantalum into the steel and the form of the tantalum in the alloy apparently affected the results. The tantalum steels were found to be very dirty and full of oxides even when melted under the best of conditions. Even in view of this fact, however, the tantalum steels seemed to be tougher than the standard types of high-speed steel."

Studies of tantalum in carbon steels have been reported by Guillet,[55] Portevin,[56] and others[57] but these investigations do not throw much light upon the subject under discussion. Apparently tantalum up to at least 8 per cent in iron-carbon alloys is in solution in the ferrite, and with carbon up to 0.6 per cent the steels are pearlitic on normal slow cooling and martensitic after quenching. The effects of tantalum on steels which are suitable for cutting tools are not generally known, although a few patents, typified by that granted to F. T. McCurdy,[58] indicate that tantalum may be useful in this field.

The seven steels containing tantalum that were tested fall into three classes. Steel E23, Table 2, is a chromium-tantalum steel similar to one previously mentioned as having been made experimentally in England. Steel E42 is a chromium-tungsten-vanadium steel in which about 6 per cent of tungsten was replaced by 6 per cent of tantalum. The steels E43, E44, and E16 contained the usual proportions of special elements, except that the vanadium was replaced by different proportions of tantalum. The results obtained with these three steels suggested that increased carbon might improve the properties, and accordingly two similar steels were made, E45 and E100, Table 2, with 0.9 and 1.4 per cent carbon, respectively.

A study was first made of the hardness of the different steels after different heat treatments and developed some interesting characteristics. There was no evidence of rehardening on tempering of the chromium-tantalum steel, E23, as is shown in Fig. 32.

The hardened samples appeared to be predominately martensitic with some undissolved particles, probably chromium carbides, as is shown in Figs. 33 (*a*), (*b*), and (*c*). Steel E42 would not harden appreciably under any of the heat treatments em-

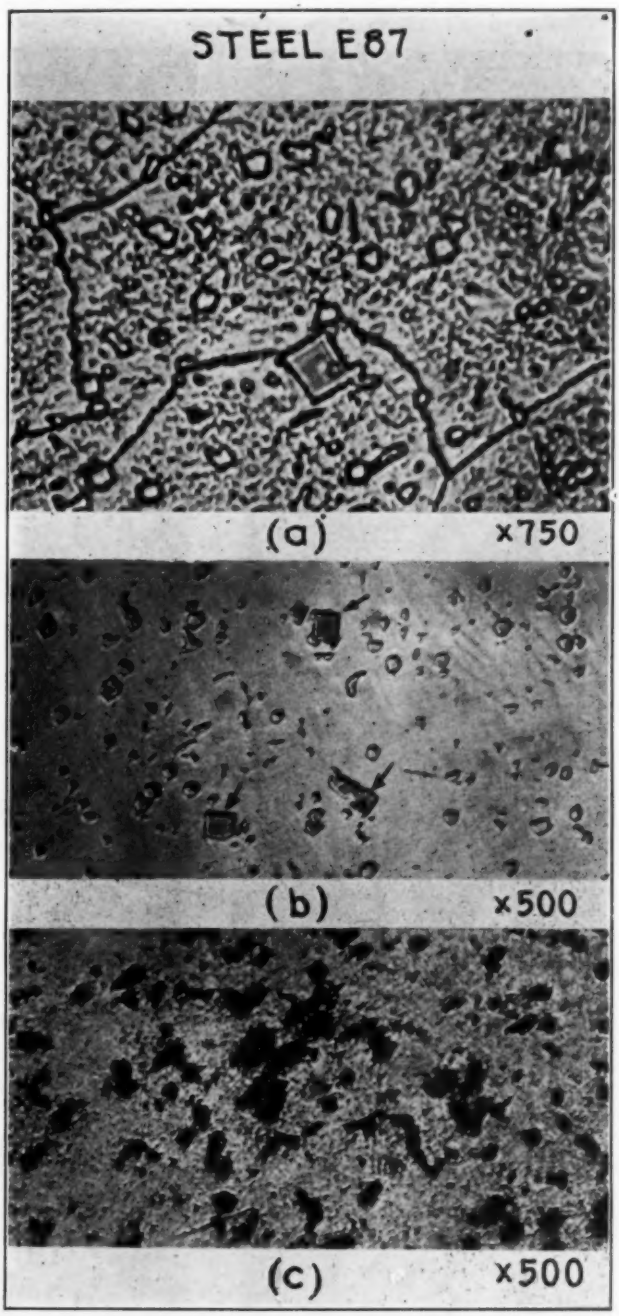


FIG. 30 STRUCTURE OF ONE OF THE HIGH-SPEED STEELS CONTAINING TITANIUM AS OIL QUENCHED FROM 2350 DEG. FAHR.
(Chemical composition is given in Table 2; *a* etched with 5 per cent HNO_3 in alcohol; *b* unetched; *c* etched in boiling solution of $KMnO_4$ (4 grams), NaOH (4 grams) in 100 cc. H_2O.)

[52] See footnote 27.
[53] Private communication.
[54] Discussion of the report referred to in footnote 27.
[55] L. Guillet, "Sur les proprietes et la constitution des aciers au tantale," *Comptes Rendus*, vol. 145 (1907), p. 327.
[56] A. M. Portevin, "Contribution to the Study of the Special Ternary Steels," Carnegie Scholarship Memoirs, vol. 1, 1919, p. 230.
[57] "An Investigation of Tantalum Steels" (for G. G. Blackwell Sons & Co., Ltd., Liverpool, England), *Iron and Coal Trades Review*, vol. 78 (1909), p. 933.
[58] U. S. Patent 1,449,338, March 20, 1923.

ployed. These included oil and water quenching from temperatures varying from 1500 to 2500 deg. fahr., followed by tempering at different temperatures up to 1400 deg. fahr. for periods up to 195 hours. The long-time tempering was carried out to ascertain whether any precipitation hardening would occur. The structure of this steel when quenched from 2350 deg. fahr. into oil is shown in Figs. 33 (*d*), (*e*), and (*f*), and comprised a large number of undissolved particles, probably carbides and tungstides in a matrix of alpha iron (Rockwell C hardness about 27) presumably containing tantalum in solid solution.

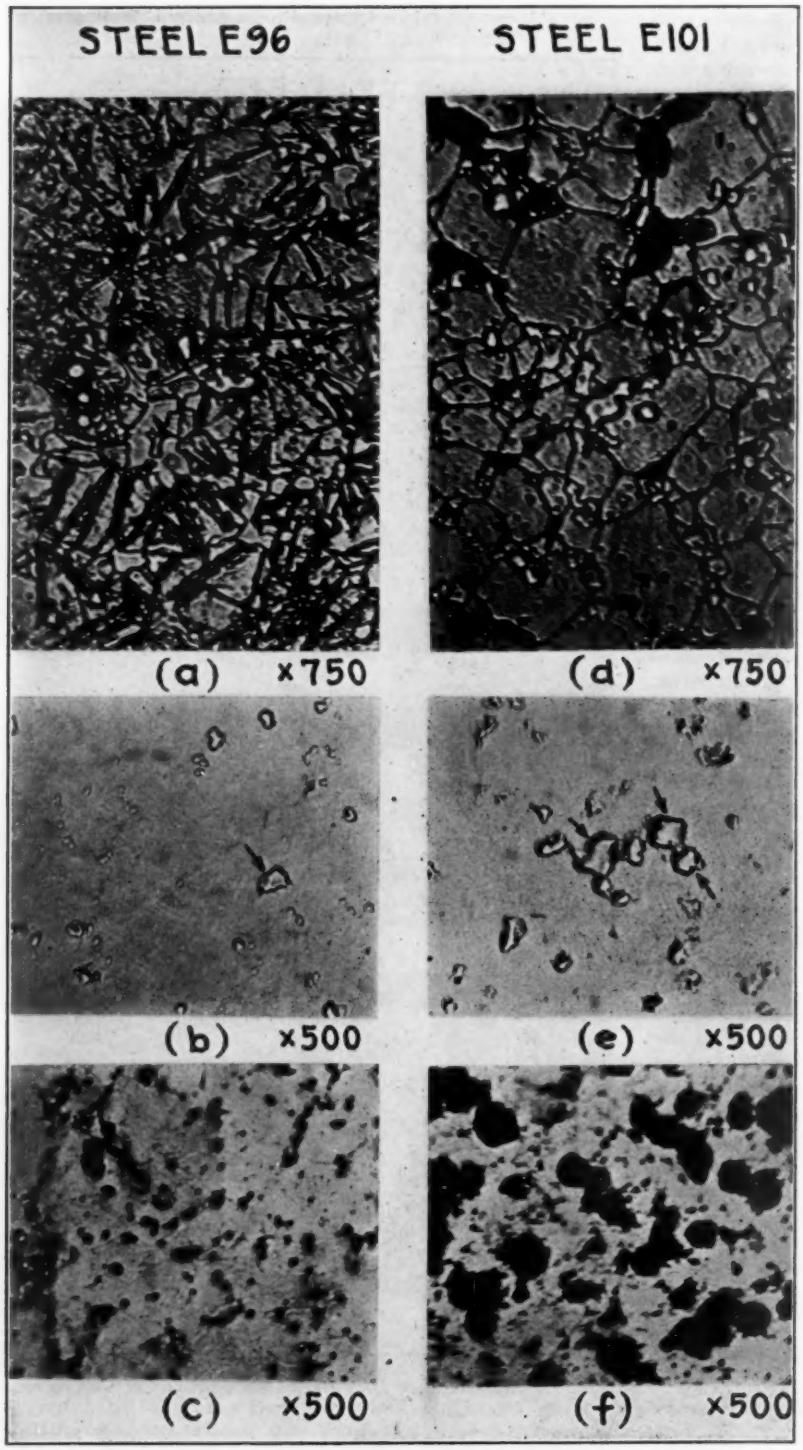


FIG. 31 STRUCTURES OF HARDENED HIGH-SPEED STEELS CONTAINING ABOUT 1.2 PER CENT C AND DIFFERENT PROPORTIONS OF TITANIUM (AND ALUMINUM)

(Compositions of the steels are given in Table 2; *a* and *d* etched with 5 per cent HNO_3 in alcohol; *b* and *e* unetched; *c* and *f* etched in boiling solution of $KMnO_4$ (4 grams), NaOH (4 grams) in 100 cc. H_2O: Samples first oil quenched from 2350 deg. fahr.)

The hardness of the steels containing the usual proportions of carbon, chromium, and tungsten (low-tungsten–high-vanadium steels) was not greatly affected under different heat treatments by 0.75 per cent or less of tantalum, except that the maximum rehardening on tempering occurred at about 1000 to 1050 deg. fahr. instead of at 1100 deg. and that the hardness of the tempered samples did not quite equal the highest hardness produced in the untempered samples. Also in the untempered samples the hardness tended to decrease with increase in quenching temperature. (Fig. 34.) With 5 per cent tantalum the hardness was less than that of the high-speed steels of customary composition when subjected to comparable heat treatments, and the hardness was more largely dependent upon the quenching temperature.

As shown in Fig. 35, the number of undissolved particles increased with increase in the tantalum. This was probably not due to any combination of tantalum and carbon, but to a decrease in the dissolving power of the austenite for the chromium and tungsten carbides, or tungstides, produced by the tantalum in solution in the iron.

The hardness and the structures (Figs. 32 and 36) of the chromium-tungsten-tantalum steel E45, containing 0.9 per cent carbon, were approximately the same as those of the chromium-tungsten-tantalum steels with 0.6 to 0.7 per cent carbon.

Perhaps the most interesting of the steels containing tantalum in addition to the customary amounts of chromium and tungsten was the one containing 1.4 per cent carbon (E100, Table 2). As shown in Fig. 32, this steel had a Rockwell C scale hardness of only about 36 when oil quenched from temperatures between 2200 and 2500 deg. fahr. When hardened from a lower temperature, 2000 deg. fahr., its hardness was about 56 and was not appreciably changed upon subsequent tempering at temperatures up to 1100 deg. fahr.

The samples which did not harden when oil quenched from 2200 to 2500 deg. fahr. did not harden appreciably when subsequently tempered at temperatures up to 1000 deg. fahr., but with increase in tempering temperature to 1100 deg. fahr. showed a surprisingly large increase in the hardness. This increase on the Rockwell C scale was from about 40 to 62, a difference of 22 points. The untempered samples showed an austenitic matrix with numerous undissolved particles at the austenite grain boundaries as is shown in Figs. 36(*d*), (*e*), and (*f*).

None of the steels containing tantalum showed as good performance as the high-speed steels of customary compositions, either with shallow cuts and fine feeds or under heavy duty. Steel E42, which would not harden, also failed to cut. Likewise the chromium-tantalum steel E23 did not show cutting properties comparable to those of the ordinary high-speed steels. The results of the lathe tests with these steels are summarized in Table 16.

The high-carbon, chromium-tungsten-tantalum steel, E100 (Table 2), which showed the very large increase in hardness when tempered at 1100 deg. fahr. after quenching from high temperatures failed to show any promise for lathe tools for either shallow cuts or heavy duty. As shown in Table 16, the tools failed in less than one minute, whereas the high-speed steels of customary composition cut for periods of 10 to 22 min. under comparable conditions. The best tool life (3.6 min.) in rough turning was obtained when steel E100 was oil quenched from 2400 deg. fahr. and subsequently tempered at 1100 deg. fahr.

The four high-speed steels containing 0.6 to 0.9 per cent carbon, in which the 2 per cent of vanadium was replaced by different proportions of tantalum, gave the best tool performance of any of the steels containing tantalum, but in no case was this as good as the performance of the customary chromium-tungsten-vanadium steel. As shown in Fig. 37, the cutting speeds of the chromium-tungsten-tantalum steels decreased with increase in the proportion of tantalum.

Tantalum does not appear to be promising as a substitute for vanadium or as an alloying element in the customary chromium-tungsten high-speed steels for lathe tools. It acted in a manner similar to aluminum and titanium in that it appeared to decrease the dissolving power of the austenite for the chromium and tungsten compounds, and so decreased the hardness and cutting speeds of the quenched lathe tools.

Steels With High Phosphorus or Sulphur

Phosphorus and sulphur are present in varying proportions in all commercial steels, and therefore it seemed desirable to determine their effects upon lathe-tool performance in connection with the study of impurities in high-speed steels for shallow cuts, already described. Furthermore, relatively large proportions of phosphorus or sulphur were inadvertently introduced, through one of the lots of ferrovanadium into some of the high-speed steels containing nickel or cobalt, and it became impracticable to interpret the results of the lathe tests with these steels without information on the effects of the phosphorus and sulphur present.

As a result of their extended experiments with roughing tools, Taylor and co-workers[59] came to the conclusion "that high phosphorus and sulphur are much less injurious to high-speed tools than they are to the carbon tools. However, these elements still exert a somewhat injurious influence upon the steel, and we therefore recommend, inasmuch as the presence of chromium and tungsten in large quantities necessarily renders high-speed tools very expensive, that the best qualities of low-phosphorus and low-sulphur iron should be used in their manufacture."

These views have received the support of a majority of the American manufacturers of high-speed tool steels, as is shown by the results of a survey made during 1922[60] of 66 lots representing

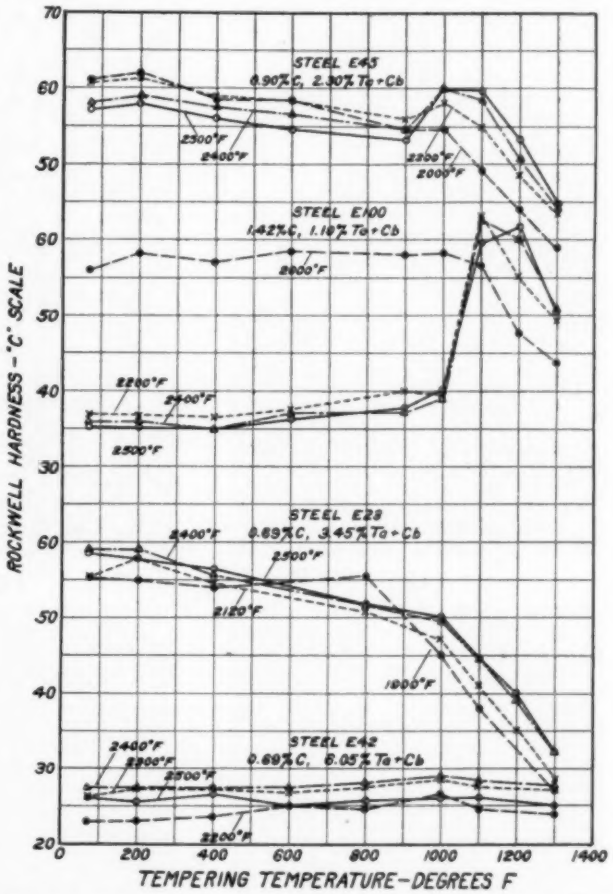


Fig. 32 Hardness of Some of the High-Speed Steels Containing Different Proportions of Tantalum (+ Columbium) When Subjected to Different Heat Treatments

(Compositions of the steels are given in Table 2. Quenching temperatures are shown in the body of the chart.)

[59] See footnote 4, par. 1087, p. 219.

[60] H. J. French and Jerome Strauss, "Lathe Breakdown Tests of Some Modern High Speed Tool Steels," Technologic Papers of the Bureau of Standards, No. 228 (1923).

TABLE 16 SUMMARY OF THE LATHE TESTS ON SOME OF THE STEELS CONTAINING TANTALUM (+ COLUMBIUM)

Steel no.	Chemical composition, Per cent C	Cr	W	V	Ta (+Cb)	Oil quenched from (deg. fahr.)	Tempered at (deg. fahr.)	Tests on forging no.	No. of tools tested	Avg. tool life, min.	Cutting speed for 90 min. tool life[1] ft. per min.
Tests with Shallow Cuts (0.010 in. depth, 0.0115 in. per rev. feed, 350 ft. per min. speed)											
E97	0.64	3.41	13.02	1.99	..	2350	1100	41	8	22.9	305
E23	0.69	4.28	...	..	3.45	2350	650	41	5	0	..
E42	0.69	4.23	8.2	1.58	6.05	Would not harden		41	..	..	..
E100	1.42	3.37	13.03	0.10	1.10	2350	1000	41	7	0.2	..
Heavy-Duty Tests (3/16 in. depth, 0.028 in. per rev. feed, 85 ft. per min. speed)											
L	0.71	3.60	12.75	1.99	..	2350	1100	17	8	11.0	63
E23	0.69	4.28	...	..	3.45	2400	650	17	6	0.1	..
E42	0.69	4.23	8.2	1.58	6.05	Would not harden			7	..	..
L	0.71	3.60	12.75	1.99	..	2350	1100	36	8	13.9[2]	57
E100	1.42	3.37	13.03	0.10	1.10	2200	1100	36	8	0.5[2]	..
E100	1.42	3.37	13.03	0.10	1.10	2300	1100	36	8	0.5[2]	..
E100	1.42	3.37	13.03	0.10	1.10	2400	1100	36	8	3.6[2]	47

[1] Computed from average tool life by means of Equation [1] of the text with $n = 1/10$ for shallow cuts and $n = 1/7$ for deep cuts.
[2] Tests made at 75 ft. per min.

39 commercial brands on the American market. The average proportions of phosphorus and sulphur were 0.023 per cent and 0.027 per cent, respectively, while the ranges were 0.004 to 0.051 per cent phosphorus and 0.009 to 0.061 per cent sulphur.

Comparison of the results in Fig. 38 with those for steel E97 in Fig. 23, shows that the Rockwell hardness of the high-speed steels was not appreciably affected by 0.058 per cent added phosphorus or 0.215 per cent added sulphur. However, the high-sulphur steels showed a large number of sulphide inclusions, Figs. 42(*a*) and (*b*), and 40, and there was evidence of phosphide-rich areas in the steel with 0.058 per cent phosphorus, Fig. 42(*c*).

The sulphide inclusions in the chromium-tungsten-vanadium steels were probably sulphides of both manganese and iron, since the 0.39 per cent manganese in steel E133 is not sufficient to take care of all of the 0.215 per cent sulphur. Similar sulphide inclusions were found in the high-sulphur high-speed steels containing nickel, although they did not have as smooth boundaries as in the steels without nickel and were interspersed with, or broken up by, white constituents, presumably the carbides and tungstides. It is possible that some of the sulphur has combined with the nickel in the high-speed steels containing this latter element, but definite evidence is lacking that this is so, and the significance, if any, of these differences in structural characteristics is not now apparent. The feature of principal interest is that evidence was obtained in the lathe tests that high sulphur was somewhat more detrimental in the high-speed steels with nickel than in those without.

In the lathe tests under heavy duty and also those under shallow cuts, summarized in Fig. 39, the steel with 0.058 per cent phosphorus (E131, Table 2) and the steels with 0.135 and 0.215 per cent sulphur showed comparable performance to the steels with much lower proportions of these elements (E129 and E97). Similarly a cobalt high-speed steel with both high phosphorus and high sulphur (E15) had a cutting speed equal to that of a similar steel with low phosphorus and sulphur (Steel A, Table 2). On the other hand, the nickel-bearing high-speed steel with 0.057 per cent phosphorus and 0.125 per cent sulphur had a lower cutting speed than similar steel with about 0.02 per cent of each of these elements.

It may therefore be said that phosphorus up to about 0.06 per cent and sulphur up to 0.215 per cent do not appear to be injurious, from the viewpoint of lathe-tool performance, when present individually or together, in the customary chromium-tungsten-vanadium steels, with or without cobalt. However, high sulphur tended to lower the cutting speeds in the presence of nickel.

Because of the possibility of segregation of the phosphorus and the introduction of numerous sulphide inclusions in high-sulphur steels, these two elements may react disadvantageously by promoting lack of uniformity and localized weaknesses. Therefore they can advisably be kept within low limits for all high-speed-steel lathe tools.

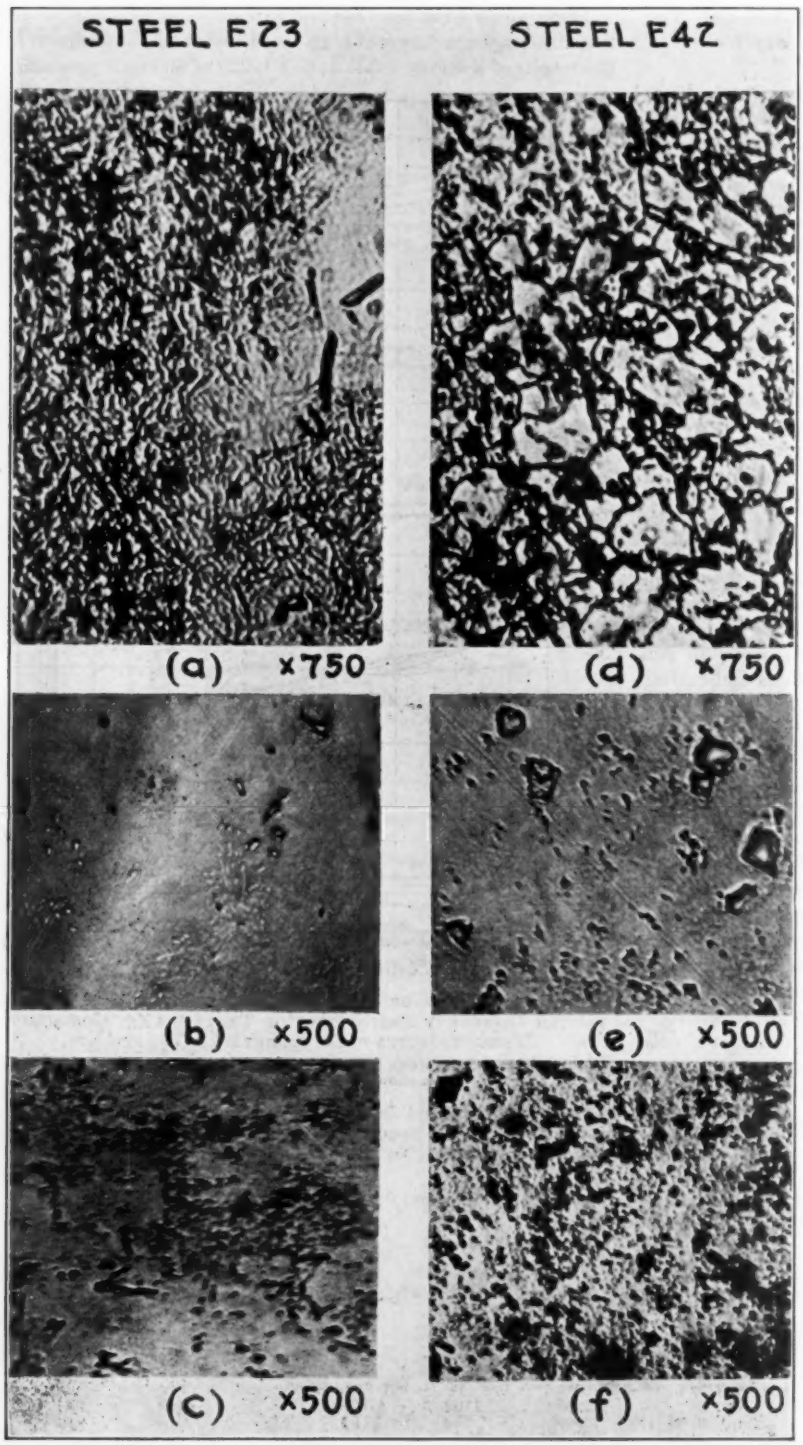


FIG. 33 STRUCTURES OF THE CHROMIUM-TANTALUM STEEL AND THE CHROMIUM-TUNGSTEN-TANTALUM-VANADIUM STEEL AS OIL QUENCHED FROM 2350 DEG. FAHR.

(Compositions of the steels are given in Table 2; *a* and *d* etched with 5 per cent HNO_3 in alcohol; *b* and *e* unetched; *c* and *f* etched in boiling solution of $KMnO_4$ (4 grams), NaOH (4 grams) in 100 cc. H_2O.)

Steels With Nickel

The close proximity of nickel and cobalt in the periodic system of the elements and recognition of the benefits derived from cobalt has frequently raised the question of substituting nickel for cobalt in high-speed tool steels.

Previously reported tests with roughing tools[61] showed that the addition of about 3¾ per cent of nickel to the customary chromium-tungsten-vanadium steels produced effects similar to those from like amounts of cobalt. However, in hardening somewhat higher temperatures had to be used for the nickel steels than for the steels without nickel to produce the best tool performance, and in this respect nickel and cobalt acted similarly. On the other hand, it was more difficult to put the high-speed steels with nickel into a machinable condition than it was with steels containing cobalt or steels without nickel or cobalt, unless an adjustment was made in the carbon content. With decrease in carbon from 0.6 or 0.7 per cent to 0.5 per cent the steels with nickel could themselves be readily machined, while the tool performance under heavy duty remained substantially the same.

These tests were all made under heavy duty and two of the nickel steels contained high phosphorus or sulphur, or both. For this reason the rough-turning tests were repeated on steels containing low proportions of phosphorus and sulphur and the results are included in Table 17 with those obtained under shallow cuts and fine feeds.

The results in Table 17 shows that the addition of 3¾ per cent of nickel to the customary chromium-tungsten-vanadium steels was beneficial for the rough-turning tools but detrimental to the tools under shallow cuts and fine feeds.

In the rough-turning tools the addition of nickel together with a 50 deg. fahr. increase in the quenching temperature produced an appreciable improvement in the performance of the high-speed steels, but the same tools were not as good under shallow cuts as the tools free from nickel which were hardened at lower temperatures.

The fact already mentioned that the high-speed steels with nickel could not themselves be readily machined, even after prolonged annealing, suggested lowering the carbon content from around 0.6 or 0.7 per cent to 0.5 per cent.

This did not affect the performance of the roughing tools appreciably, as is shown in Table 17, but was detrimental in the tools used under shallow cuts.

[61] See footnote 27.

XII—SUMMARY AND CONCLUSIONS

1 A method is described for testing lathe tools under shallow cuts and fine feeds. It is based upon the fact that when two tools are set at equal depths in one tool holder the second or "trailing" tool will not cut so long as the "leader" or cutting tool shows no wear. With the carbon- and high-speed-steel tools used, the second tool began to cut when the leader had worn 0.001

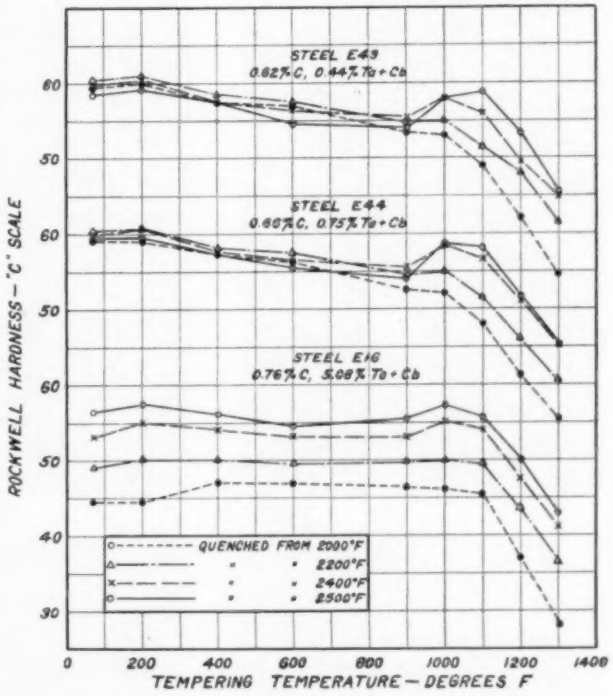


Fig. 34 Hardness of Some of the High-Speed Steels Containing Different Proportions of Tantalum (+ Columbium) When Subjected to Different Heat Treatments

(Compositions of the steels are given in Table 2.)

TABLE 17 LATHE-TOOL PERFORMANCE OF HIGH-SPEED STEELS WITH AND WITHOUT NICKEL

Steel no.	Chemical composition, per cent							Oil quenched[1] from (deg. fahr.)	Forging no.	Cutting conditions: Speed, ft. per min.	Cutting conditions: Feed, in. per rev.	Cutting conditions: Depth of cut, in.	No. of tools tested	Avg. tool life, min.	Cutting speed for 90 min. tool life,[2] ft. per min.
	C	Cr	W	V	P	S	Ni								
Tests Under Heavy Duty															
E129	0.63	3.94	13.03	2.00	0.017	0.023	..	2350	42	100	0.028	3/16	5	11.4	74.5
E97	0.64	3.41	13.02	1.99	0.006	0.015	..	2350	42	100	0.028	3/16	5	12	75
E130	0.61	3.94	13.03	1.90	0.017	0.023	3.81	2350	42	100	0.028	3/16	5	17.5	79
								2400	42	100	0.028	3/16	5	22.9	82.5
E14	0.69	3.64	13.75	1.92	0.057	0.125	3.70	2350	42	100	0.028	3/16	5	8.9	72
								2400	42	100	0.028	3/16	5	12.3	75.5
L	0.71	3.60	12.75	1.99	0.029	0.026	..	2350	18	85	0.028	3/16	8	11.0	63
E14	0.69	3.64	13.75	1.92	0.057	0.125	3.70	2400	18	85	0.028	3/16	6	11.4	63.5
E41	0.51	3.85	12.72	1.95	0.019	0.020	3.54	2400	18	85	0.028	3/16	6	12.5	64.5
Tests Under Shallow Cuts															
E129	0.63	3.94	13.03	2.00	0.017	0.023	..	2350	41	380	0.0115	0.010	6	23.7	333
E97	0.64	3.41	13.02	1.99	0.006	0.015	..	2350	41	380	0.0115	0.010	6	19.2	326
E130	0.61	3.94	13.03	1.90	0.017	0.023	3.81	2350	41	380	0.0115	0.010	6	6.8	294
								2400	41	380	0.0115	0.010	6	11.0	308
E14	0.69	3.64	13.75	1.92	0.057	0.125	3.70	2350	41	380	0.0115	0.010	6	6.8	294
								2400	41	380	0.0115	0.010	6	5.5	288
E97	0.64	3.41	13.02	1.99	0.006	0.015	..	2350	41	380	0.0115	0.010	8	22.8	332
E41	0.51	3.85	12.72	1.95	0.019	0.020	3.54	2400	41	380	0.0115	0.010	8	5.6	288
E97	0.64	3.41	13.02	1.99	0.006	0.015	..	2350	41	380	0.0115	0.010	8	16.4	321
E14	0.69	3.64	13.75	1.92	0.057	0.125	3.70	2400	41	380	0.0115	0.010	8	5.5	288
E108	0.66	3.90	18.25	1.12	0.027	0.012	..	2400	41	380	0.0115	0.010	7	17.8	324
E22	0.61	3.66	17.40	1.02	0.043	0.073	3.71	2450	41	380	0.0115	0.010	7	5.2	287
E97	0.64	3.41	13.02	1.99	0.006	0.015	..	2350	41	400	0.0115	0.005	6	14.6	334
E22	0.61	3.66	17.40	1.02	0.043	0.073	3.71	2450	41	400	0.0115	0.005	6	7.6	313

[1] All tools annealed at 1600 to 1650 deg. fahr.; tempered 30 to 45 min. at 1100 deg. fahr. after hardening.

[2] Computed from Equation [1] of the text with $n = 1/7$ for deep cuts and $n = 1/10$ for shallow cuts.

All tests made dry with tools of the form shown in Fig. 5. The tests in each block constitute a complete run at one time in sequence at different diameters of the test forgings.

to 0.002 in., and at this point the leader or test tool was considered to have failed. All subsequent comments on turning with shallow cuts and fine feeds are based on this end point, but greater wear can be made to represent tool failure by using a shallower setting for the second tool than is used for the cutting tool.

2 Tests were made dry at different cutting speeds, feeds, and depths of cut on nickel-steel forgings with tensile strengths of 80,000 to 100,000 lb. per sq. in. to give a broad background for the interpretation of the results of tests of different tool steels, first heat treated in various ways. The results could be represented approximately by the following equations in which V is the cutting speed, T the tool life, F the feed, D the depth of cut, A the area of cut ($=DF$), and c, K, K_1, K_2, and n are constants.

For high-speed-steel tools,

$$VT^{1/10} = c \quad [1]$$

$$V = K_1 - K_2(DF) = K_1 - K_2A \quad [2]$$

For carbon-steel tools,

$$V = \frac{K}{DF} = \frac{K}{A} \quad [3]$$

These equations are not to be construed to represent the true laws of cutting since the cutting speed is probably not affected equally by variations in the feed and the depth of cut. However, they represent approximately the results of the experiments made with depths of cut of 0.005 to 0.020 in. and feeds of 0.0115 to 0.0204 in. per rev.

3 In tests of short duration, where tool failure occurred in about 2 to 10 min. the tool life was increased somewhat more by the use of water than by lard oil, but in tests of about 50 min. duration, under the same feed and depth of cut but lower cutting speeds, these two liquids produced effects of the same magnitude. The increases in tool life from the use of these liquids were not large in any case, but the finish on the work piece at the end of the cut was better with the liquids than without.

4 Tests with tools of different forms and angles showed that the successful application of the described method of test was not dependent upon having the broad-nose tool used in a majority of the experiments. Tools with a plan angle of 65 deg. had a longer life than the broad-nose tools, but the finish produced on the nickel steels in dry turning did not appear to be as good. The best tool life in the broad-nose tools was obtained with a back slope of 30 deg.; a side slope of 0 deg. was better than one of 8 deg.

5 The cutting speed of quenched carbon-steel tools was not affected appreciably by variations in carbon content from 0.75 per cent to 1.3 per cent nor by subsequent tempering at temperatures up to 375 deg. fahr., which did not lower the hardness; the cutting speed of the carbon-steel tools was equal approximately to that of a quenched "oil-hardening" tool steel, and only slightly lower than the cutting speed of a steel containing 1.3 per cent carbon and $2^3/_4$ per cent tungsten.

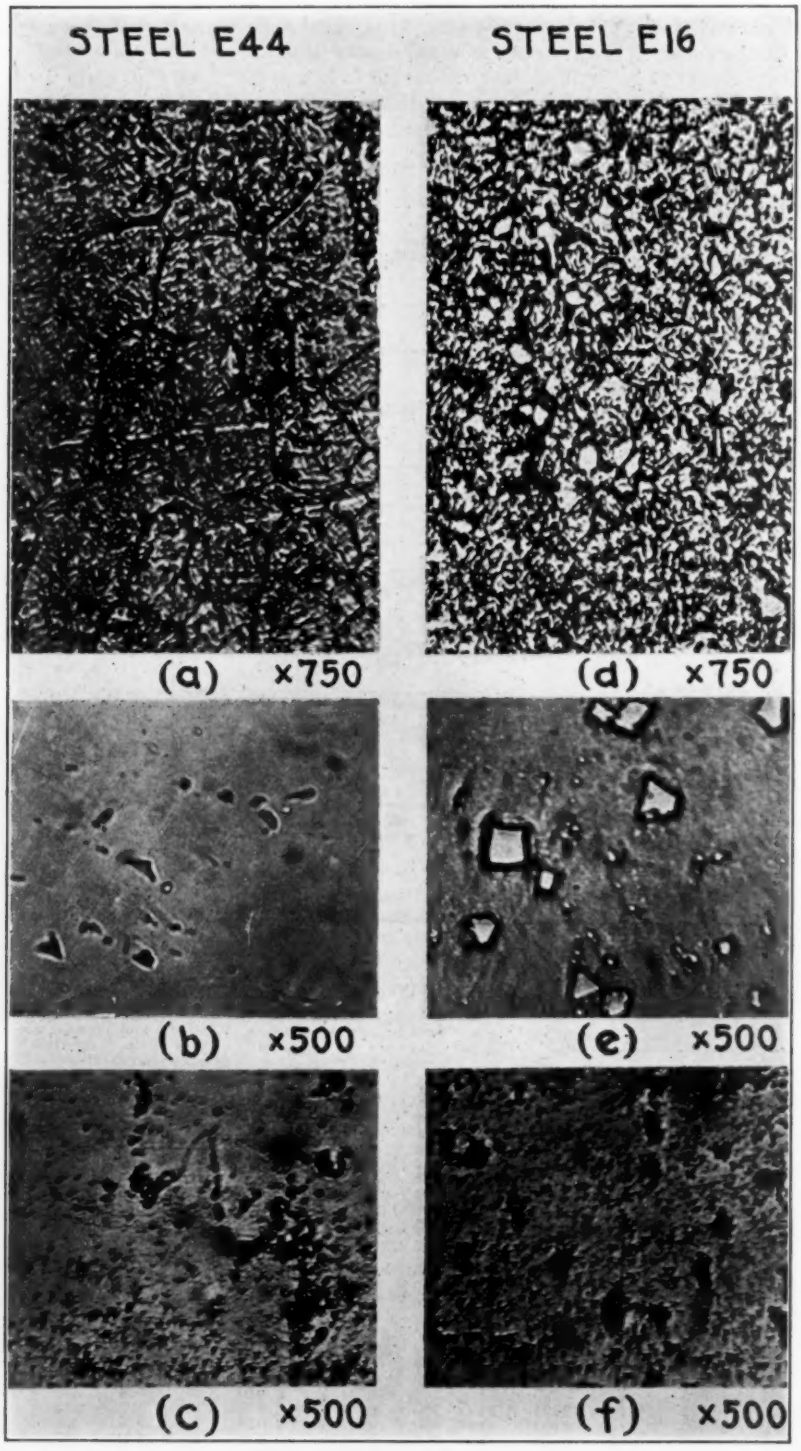


FIG. 35 STRUCTURES OF TWO OF THE CHROMIUM-TUNGSTEN-TANTALUM STEELS AS OIL QUENCHED FROM 2350 DEG. FAHR.

(Compositions of the steels are given in Table 2; *a* and *d* etched with 5 per cent HNO_3 in alcohol; *b* and *e* unetched; *c* and *f* etched in boiling solution of $KMnO_4$ (4 grams), NaOH (4 grams) in 100 cc. H_2O.)

6 The cutting speed of carbon-steel tools was lower in all cases than that of high-speed-steel tools, but the differences between the two decreased with decrease in the areas of cut in dry turning.

7 The heat treatments which resulted in the best roughing-tool performance for high-speed steels of customary compositions also resulted in superior performance under shallow cuts and fine feeds. These treatments comprised oil quenching from the highest practical temperatures, followed by tempering to convert the larger part of the retained austenite to martensite.

8 Of twelve elements added in different proportions to chromium-tungsten or chromium-tungsten-vanadium high-speed steels only one, cobalt, produced decidedly beneficial results. Molybdenum and nickel offered promise under certain conditions, while the remainder either had a negligible effect or were definitely deleterious from one viewpoint or another.

9 Cobalt improved the performance of the high-speed-steel tools both under shallow cuts and under heavy duty, but the maximum benefits were obtained only with high hardening temperatures. The percentage gain from the addition of cobalt was somewhat greater in rough turning than with shallow cuts and fine feeds, but increase in cobalt above about 5 per cent did not produce improvements commensurate with those resulting from 3.5 to 5 per cent and high hardening temperatures.

10 Replacement of part or all of the tungsten in high-speed steels by molybdenum, in the ratio of 1 part molybdenum to $2^1/_2$ parts of tungsten, produced steels having performance comparable to that of the tungsten steels. Such substitution should be useful in case of a depleted tungsten supply, but is not advocated at the present time since there was some evidence of irregular performance in the high-molybdenum steels and their hot-working properties did not seem to be as good as those of the tungsten steels. However, a steel with 7 per cent molybdenum and no tungsten had one advantage over the tungsten steels for roughing tools in that its hardness and performance were not so largely affected by variations in the hardening temperatures.

11 The addition of $3^1/_4$ per cent of nickel to the customary chromium-tungsten-vanadium steels was beneficial for the rough-turning tools, particularly when combined with a 50 deg. fahr. increase in the hardening temperatures, but was detrimental to the tools used under shallow cuts and fine feeds and adversely affected the machining properties of the high-speed steel itself. Lowering the carbon from 0.6 or 0.7 per cent to 0.5 per cent improved the machining properties without affecting the performance of the roughing tools, but was detrimental to the tools used under shallow cuts.

12 Each of the four elements, arsenic, antimony, copper, and tin, adversely affected the tool performance of high-speed steels under shallow cuts, and the magnitude of the decrease became greater as the proportions of these elements increased. Copper

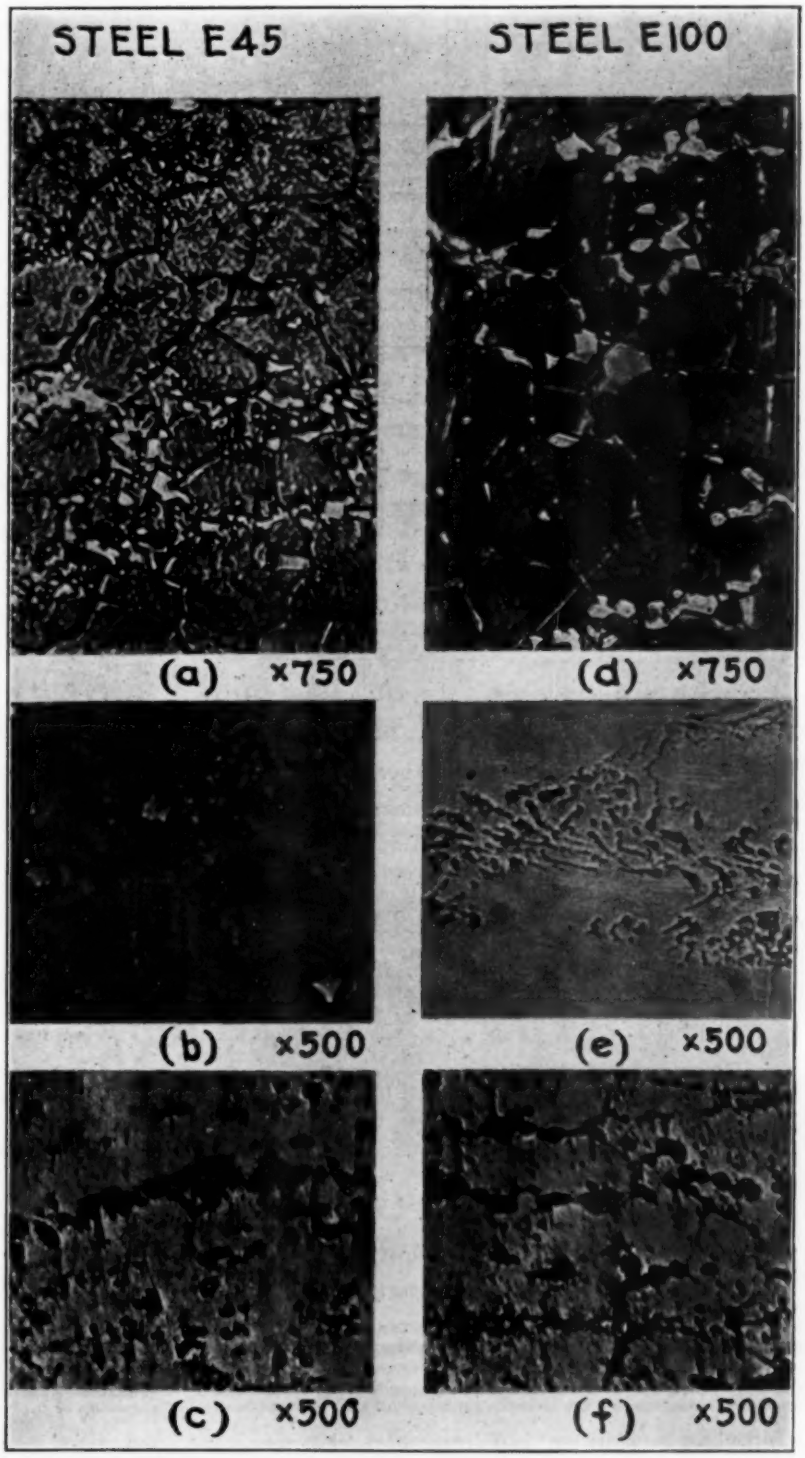


FIG. 36 STRUCTURES OF TWO OF THE HIGH-CARBON STEELS CONTAINING CHROMIUM, TUNGSTEN, AND TANTALUM WHEN OIL QUENCHED FROM 2350 DEG. FAHR.
(Compositions of the steels are given in Table 2; *a* and *d* etched with 5 per cent HNO_3 in alcohol; *b* and *e* unetched; *c* and *f* etched in boiling solution of $KMnO_4$ (4 grams), NaOH (4 grams) in 100 cc. H_2O.)

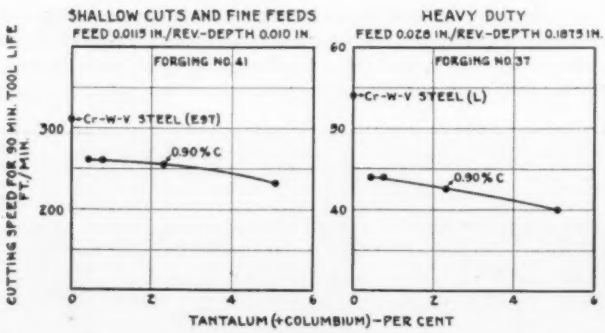


FIG. 37 EFFECT OF TANTALUM (+ COLUMBIUM) ON THE CUTTING-SPEED OF HIGH-SPEED-STEEL TOOLS UNDER SHALLOW CUTS AND UNDER HEAVY DUTY

(Compositions of the tools and their heat treatment are given in Table 2; properties of the forgings are given in Table 3. All tests were made dry.)

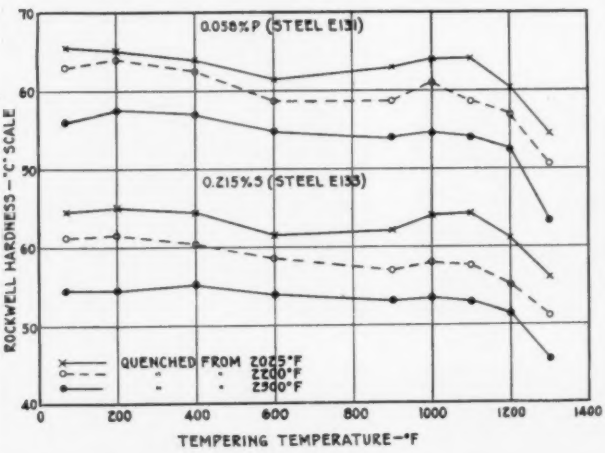


FIG. 38 HARDNESS OF THE HIGH-SPEED STEELS CONTAINING HIGH PHOSPHORUS OR HIGH SULPHUR WHEN SUBJECTED TO DIFFERENT HEAT TREATMENTS

(Compositions of the steels are given in Table 2.)

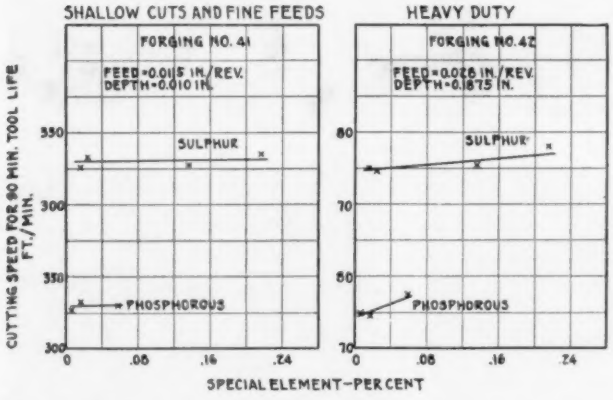


FIG. 39 EFFECTS OF PHOSPHORUS AND SULPHUR ON THE CUTTING SPEEDS OF HIGH-SPEED STEEL TOOLS UNDER SHALLOW CUTS AND UNDER HEAVY DUTY

(Compositions of the tools and their heat treatments are given in Table 2; properties of the forgings are given in Table 3. All tests were made dry.)

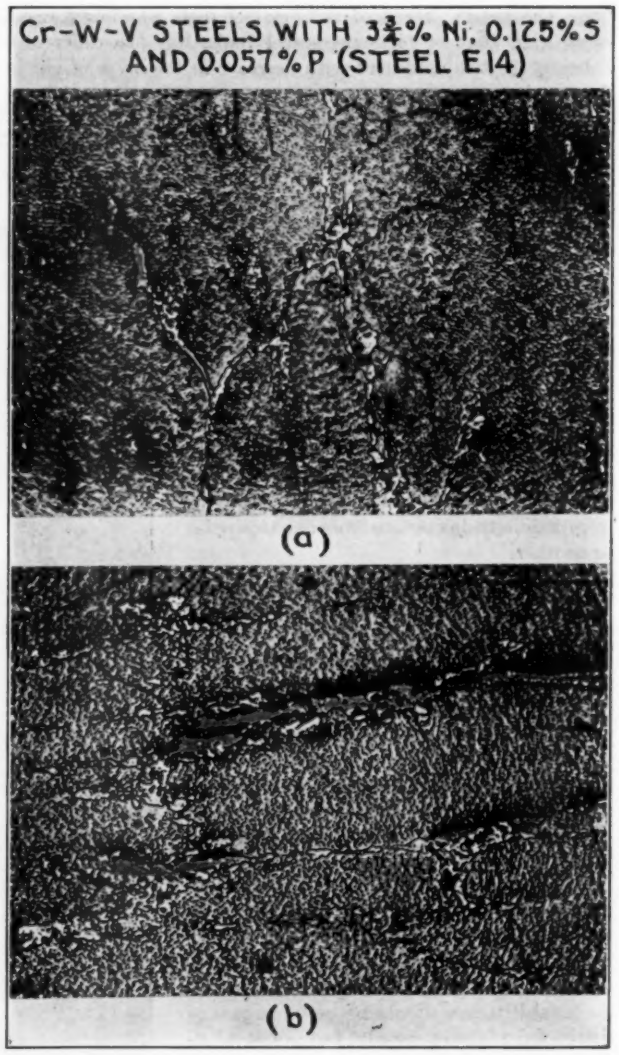


FIG. 40 STRUCTURES OF HARDENED HIGH-SPEED STEEL CONTAINING 3¾ PER CENT NICKEL AND HIGH PHOSPHORUS AND SULPHUR ×500

(Samples oil quenched from 2350 deg. fahr., not tempered; *a*, etched with 5 per cent HNO_3 in alcohol; *b*, etched with 2 per cent HF in water.)

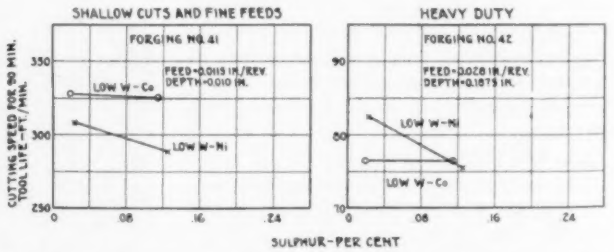


FIG. 41 EFFECTS OF SULPHUR ON THE CUTTING SPEEDS OF HIGH-SPEED-STEEL TOOLS CONTAINING NICKEL OR COBALT WHEN TESTED UNDER SHALLOW CUTS AND ALSO UNDER HEAVY DUTY

(Compositions of the tools and their heat treatments are given in Table 2; properties of the forgings are given in Table 3. All tests were made dry.)

was the least harmful; next in order came tin, while arsenic and antimony were the most objectionable.

13 The effects of these four elements upon the performance of roughing tools did not necessarily correspond to those observed with shallow cuts. The 0.8 per cent arsenic additions lowered the cutting speed, but the addition of 0.4 per cent antimony or 0.5 per cent or less of tin had no measurable effect. Higher proportions of tin lowered the cutting speeds. The high-speed steels containing 0.36 to 1.77 per cent copper showed slightly better performance than the corresponding steels without copper.

14 The steels containing 0.4 per cent antimony, 0.8 per cent or more of copper, or 0.8 per cent arsenic did not have good hot-working properties, illustrated by numerous corner cracks on the bars, while those containing 1.7 per cent antimony or 1.8 per cent tin showed a high degree of hot shortness and could not be forged or rolled. Also the steel with 1.77 per cent copper could itself be machined only with difficulty in the annealed condition.

15 Phosphorus up to about 0.06 per cent and sulphur up to 0.215 per cent did not appear to be injurious, from the viewpoint of lathe-tool performance of the customary chromium-tungsten-vanadium steels, with or without cobalt. However, high sulphur tended to lower the cutting speeds in the presence of 3¾ per cent nickel. Because of the possibility of segregation of the phosphorus and the introduction of numerous sulphide inclusions in high sulphur steels, these two elements can advisedly be kept within low limits for all high-speed-steel lathe tools.

16 Aluminum adversely affected the performance of the high-speed-steel tools both with shallow cuts and under heavy duty. It was one of the few metals considered which, in proportions around 0.3 per cent produced a measurable decrease in the cutting speeds in rough turning. This decrease became greater as the proportion of the aluminum was increased, and with 0.8 per cent the drop in cutting speed was greater than that produced by equal proportions of any of the other elements considered. These changes were accompanied by decrease in the hardness of the quenched steels, probably through decrease in the dissolving capacity of the aluminum-iron solid solution for carbon, chromium, tungsten, and vanadium. With 0.8 per cent aluminum there was also evidence of a low-melting eutectic in samples quenched from 2350 deg. fahr.

17 Titanium was another of the elements which appeared to lower the dissolving capacity of the austenite, and as a result the hardness and the cutting speeds of the high-speed-steel tools decreased with increase in the titanium. Its interference was lessened, probably through the formation of less harmful carbides, instead of solution as titanium in the austenite, by increasing the carbon content of the steel.

18 Tantalum did not appear to be promising as a substitute for vanadium or as an alloying element in the customary chromium-tungsten high-speed steels for lathe tools. It acted in a manner similar to aluminum and titanium in that it appeared to decrease the dissolving power of the austenite for the chromium and tungsten compounds and so decreased the hardness and cutting speeds of the quenched lathe tools.

XIII—ACKNOWLEDGMENTS

Acknowledgments are due to a number of the authors' associates as follows: to C. F. Raab, machinist, whose care in grinding all of the tools and help in carrying out many of the lathe tests contributed appreciably to the consistent results obtained; to W. V. Magruder, laboratory aid, for carrying out many of the heat treatments, as well as hardness and lathe tool tests; to H. K. Herschman, associate metallurgist, and S. J. Rosenberg, assistant metallurgist, for the preparation of the micrographs; and to H. Bright, associate chemist, for the chemical analysis of the tools that were necessary for the work of carrying on the various operations.

Discussion

ORLAN W. BOSTON.[62] Unquestionably the paper furnishes information on the subject of turning with shallow cuts at high speeds which has long been needed. It seems rather unusual that the results of the dynamometer tests to show a relation between vertical or horizontal forces on the tool and the tool life

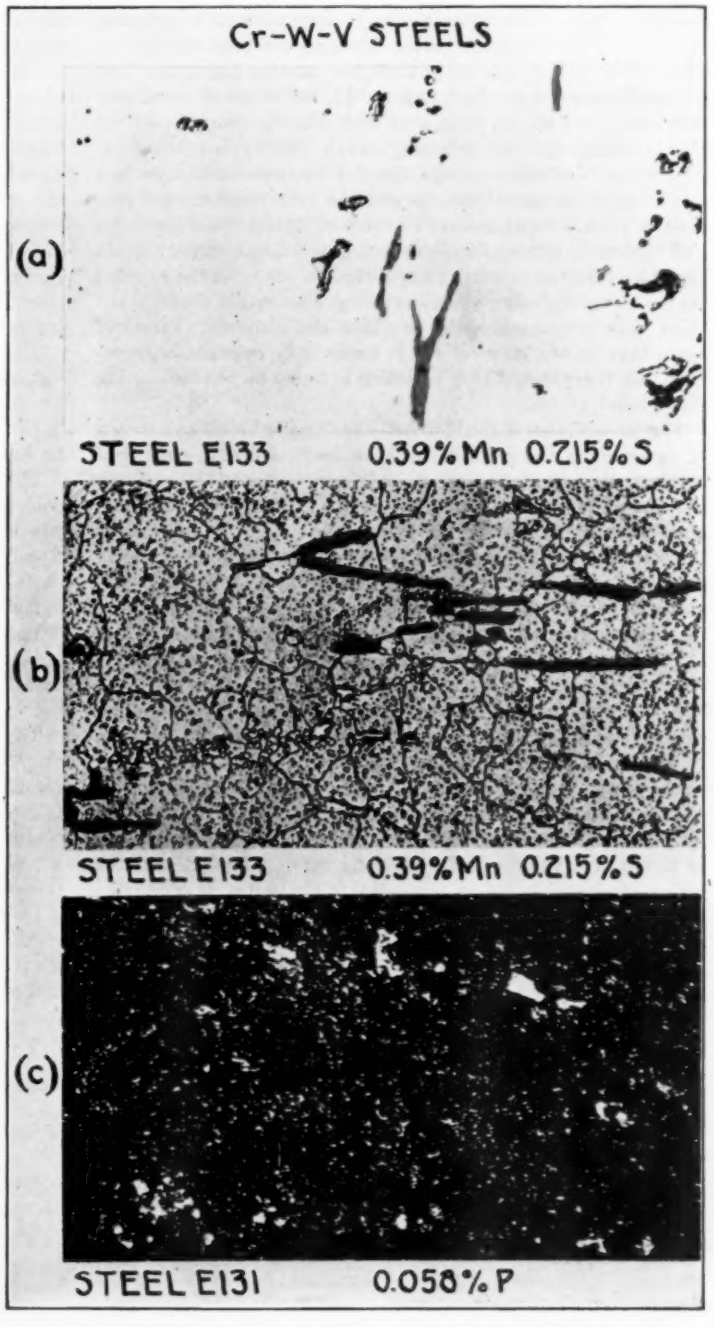


FIG. 42 STRUCTURES OF HARDENED HIGH-SPEED STEELS CONTAINING HIGH PHOSPHORUS OR HIGH SULPHUR ×500

(Samples oil quenched from 2350 deg. fahr., not tempered; *a*, unetched; *b*, etched with 5 per cent HNO_3 in alcohol; *c*, etched with Stead's reagent.)

[62] Professor of Shop Practice, University of Michigan, Ann Arbor, Mich. Mem. A.S.M.E.

were not more decisive. Obviously, during the wear of the tool the shape of the tool is altered. Where a ductile material is cut the tool failure is usually a result of a cupping action which wears gradually toward the cutting edge until the cutting edge is insufficiently supported. During this cupping action the rake, back of the cutting edge, is very materially increased up to the point of failure or the breaking down of the cutting edge. The writer has no information on this point, but has observed many times in turning with rather small cuts, say 0.100 in. by 0.0125 in. feed, that with a newly ground tool the chip is stringy and not definitely coiled. This chip is also blue. As the tool face begins to cup, the chip becomes broken up into small helical or spiral sections and the blue color merges into a straw color. Further wear of the tool causes the chips to be well broken up into small spirals and practically colorless. This condition maintains during most of the tool life. As the cupping nears the cutting edge and the cutting edge spalls slightly, the chips again become irregular in shape and somewhat torn and again take on the blue color. It seems only reasonable, therefore, that there should be a variation in forces on the tool during this whole process.

The introduction of the "leader" and "trailer" tools as a means of determining the point of tool failure in finishing cuts is of considerable importance, as no satisfactory way of determining the time of failure has previously been reported. The question may be asked as to why the broad-nosed tool was selected as the form for the best tool. This form does not seem to be of general use commercially. The results, however, would apparently not be altered by the use of this shape, as the other tool shapes give similar but slightly different values.

The results showing the effect of cutting speed on tool life show some variation in the exponent of the equation $VT_n = c$. The writer wonders if this variation is not due to the actual cutting condition rather than to experimental error; that is, is there not a gradual merging of the value of the exponent from $^1/_7$ for roughing cuts to $^1/_{12}$ for finishing cuts, and if so, what is the nature of this merging curve, and how is it influenced by depth and feed? There still appears to be some question as to the final value of n for finishing cuts. The fact that the carbon-steel tool failed in less than five minutes or continued to cut for 90 or more minutes without sign of failure is again a matter which should be explained further.

It is perhaps unfortunate that the authors did not carry out their experiments a little further with a view to establishing the laws of cutting with particular reference to the influence of the depth and feed which make up the cross-sectional area of the chip. Apparently not much greater experimental work would have been needed. This question is continually raised. Taylor's work, in spite of its age, is still one of the leading forces tending to show the influence of each of the variables rather than their product. This point has been discussed very competently by George Kiebel, M.E., of the Eastern Chinese Railway,at Harbin, in a paper, "Diagrams for Metal Turning Lathes," giving a precise method of the most advantageous utilization of tool and lathe as reported to a technical meeting of the Engineers Locomotive Society of the Chinese Eastern Railway on January 5, 1929. In this paper Mr. Kiebel lays great emphasis on the independent use of the depth and feed, rather than the area of cut. It is known that thick chips are removed more efficiently considering power than thin ones, and yet it is also known, as pointed out under the conclusions of Ripper and Burley, on the seventh page, that if the area of cut is kept constant, a higher associated cutting speed is obtainable when the cut is deep and the feed fine.

The authors' conclusions as to the effect of feed, depth of cut, and area of cut on the cutting speed for a 90-minute tool life for carbon-steel tools are extremely interesting. The relation of these curves to those for high-speed steel tools should be continued for smaller cuts.

The authors' conclusions as to the influence on tool life of back and side slope are also interesting. It is not clear, however, whether it is meant that the tool having the greatest speed for 90-minute tool life is one having 0-deg. side slope and 30-deg. back slope or whether these optimum angles were determined independently. If they were determined independently, might it not be possible that their combination might not yield the optimum results? The power would be lowered still further with an increase in the true rake, so it must be concluded that the "power" and "tool-life" factors of a tool are not in agreement.

The investigation on the influence of a coolant, representing each of the three general classes, corresponds in general with the results previously reported by the authors for rough cutting. It is unfortunate that further work was not done to determine positively the influence of the coolants on the cutting speed for a tool life greater than 50 minutes. This undoubtedly will be the subject of further investigation.

In general, the writer feels that the authors are to be commended on the thoroughness of their investigation and the clear manner in which their results are presented. Certainly, many of the points about metal cutting under the conditions of fine cuts have been cleared up and a great deal of definite information has been added to the long story of metal cutting.

MSP-52-7

A Study of Tin-Base Bearing Metals—II

By G. B. KARELITZ,[1] EAST PITTSBURGH, PA., and O. W. ELLIS,[2] TORONTO, ONT.

This paper is a continuation of one presented by the authors at the Pittsburgh Meeting of the A.S.M.E. in 1928, and deals with the mechanism of wiping of babbitt linings, with certain phenomena observed during the casting of tin-base alloys, and with the effects of cold work on them. It is shown that wiping of babbitts is a result of the upper layer of the lining's reaching the solidus temperature, when the constituent with the lowest melting temperature liquefies, the babbitt becomes "mushy," and is therefore wiped by the journal. The appearance of the castings of various chemical composition is discussed, and the variation in hardness and microstructure due to cold work is given.

THE authors' paper on the properties of tin-base bearing metals presented before the Society in 1928[3] dealt with the metallurgical investigation of a series of alloys of tin, antimony, and copper, and with the strength of these alloys at low and elevated temperatures. This second part of the study concerns itself with the nature of babbitt failure in bearings, which generally takes the form of "wiping." It can be observed in bearings, during the early stages of failure, that metal is dragged along by the journal. Frequently beads of metal are present, which, it appears, would indicate that melting has taken place. However, it has not hitherto been proved whether melting is the cause of wiping or is a result of a temperature rise following the destruction of the bearing surface and a consequent increase of friction. The latter is considered to be feasible, since it has been shown that babbitts lose their strength to a marked degree at temperatures above, say, 100 deg. cent. It seemed probable that should an occasional disturbance in lubrication take place and high local friction occur in a spot of metal-to-metal contact, the babbitt might be heated and, getting weak, be "cold worked" by the journal.

Apparatus Used for Experiments

The testing machine shown in Figs. 1 and 2 was designed with a view to approximate as closely as practicable the conditions of wiping in actual bearings. The test journal had an interchangeable outer sleeve in order to allow various shaft materials to be employed. In the tests described below a standard shaft material was used, having a composition: C, 0.3 to 0.4 per cent; Ni, 1.0 to 1.5 per cent; Cr, 0.45 to 0.75 per cent; Mn, 0.5 to 0.8 per cent; P, 0.04 per cent maximum; S, 0.045 per cent maximum. The journal was ground true to 0.0002 in. It was mounted on roller bearings and was connected by a flexible coupling to a variable-speed motor. A wide range of speeds was attained by the use of Ward Leonard control. A recording torsiometer was provided which could be mounted in place of the coupling; however, it was found that for the work at hand sufficient accuracy could be obtained by recording the field and armature currents in the motor, which was carefully calibrated for torque.

The test bearings were mounted in a very rigid frame made in two halves bolted together. The load was applied through a spring dynamometer, the maximum load being 5000 lb. A flexible arrangement of the loading gear excluded eccentricity of load application, while transverse stops on the frame prevented vibration in the event of resonant condition occurring.

The test bearings (Fig. 3) were made of bronze lined with the materials under test. The diameter of the journal was 5.000 in. The length of the bearings was 2 in., the bearing being in fact a rather narrow ring split in two on its diameter. This shape was chosen to insure the absence of an efficient load-carrying oil film and the prevalence of boundary lubrication, these test conditions being of most interest to the authors. As seen in Fig. 4, the bearings were placed in the frame with the split at an angle of 30 deg. to the frame joint. Lubrication was supplied through a hole registering with a duct in the frame by an oil cup through a needle valve. The oil cup was calibrated and the oil feed could therefore be conveniently regulated.

The bearings were machined to a clearance of 0.011 in. within an accuracy of ±0.003 in. The influence of temperature on the clearance was checked by consecutive heating and cooling of the bearing frame with an unbabbitted ring assembled in it, a glycerine bath being used for heating; the inner diameter of the bearing was measured in hot and cold condition. Table 1 gives these measurements.

TABLE 1 INFLUENCE OF TEMPERATURE ON BEARING CLEARANCE

Condition of frame	Diameter normal to ring split, in.	Diameters near line of ring split, in.	
Room temperature	5.186	5.183	5.184
Heated to 120 deg. cent.	5.191	5.188	5.189
Cooled to room temperature	5.186	5.183	5.184
Second heat to 120 deg. cent.	5.191	5.189	5.188
Cooled to room temperature	5.1855	5.183	5.184
Third heat to 120 deg. cent.	5.191	5.1885	5.188
Cooled to room temperature	5.186	5.1835	5.184

It will be seen that the increase of bearing diameters in this case was equal to the expansion of the steel bearing frame, which is natural taking into consideration its rigidity. Since there was not much difference in temperature between the journal and the bearing frame, it can be said that in these tests the clearance was practically without change.

General Procedure Employed in Wiping Tests

After preliminary observations the authors selected the following procedure of tests designed to bring about slight wiping of the lining in a manner convenient for observation. The bearing was "run in" for periods of from one to three days. Now and again during this period the bearing was dismantled for inspection, all high spots being scraped until a definite seat of approximately two inches long formed at the bottom. The load was increased in steps up to 2000 lb., while a constant speed of 300 r.p.m. was maintained. The armature current after running in was quite steady, serving as an indication of the satisfactory condition of the bearing surface. Oil was fed at a rate from 10 to 20 drops per minute (0.5 to 1.0 cc. per min.).

A special oil of light viscosity and containing 10 per cent of lard oil was used with a view to decreasing the effect of a load-carrying viscous film and providing high oiliness of the lubricant.[4] It is worth while noting that an analysis of the oil drained off the

[1] Research Department, Westinghouse Electric & Manufacturing Co. Mem. A.S.M.E.

[2] Ontario Research Foundation, Toronto, Canada.

[3] Trans. A.S.M.E., vol. 50, no. 18, May-August, 1928, paper MSP-50-11.

Presented at the Annual Meeting, New York, December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

[4] The oil was obtained through the courtesy of the United Railways of Baltimore.

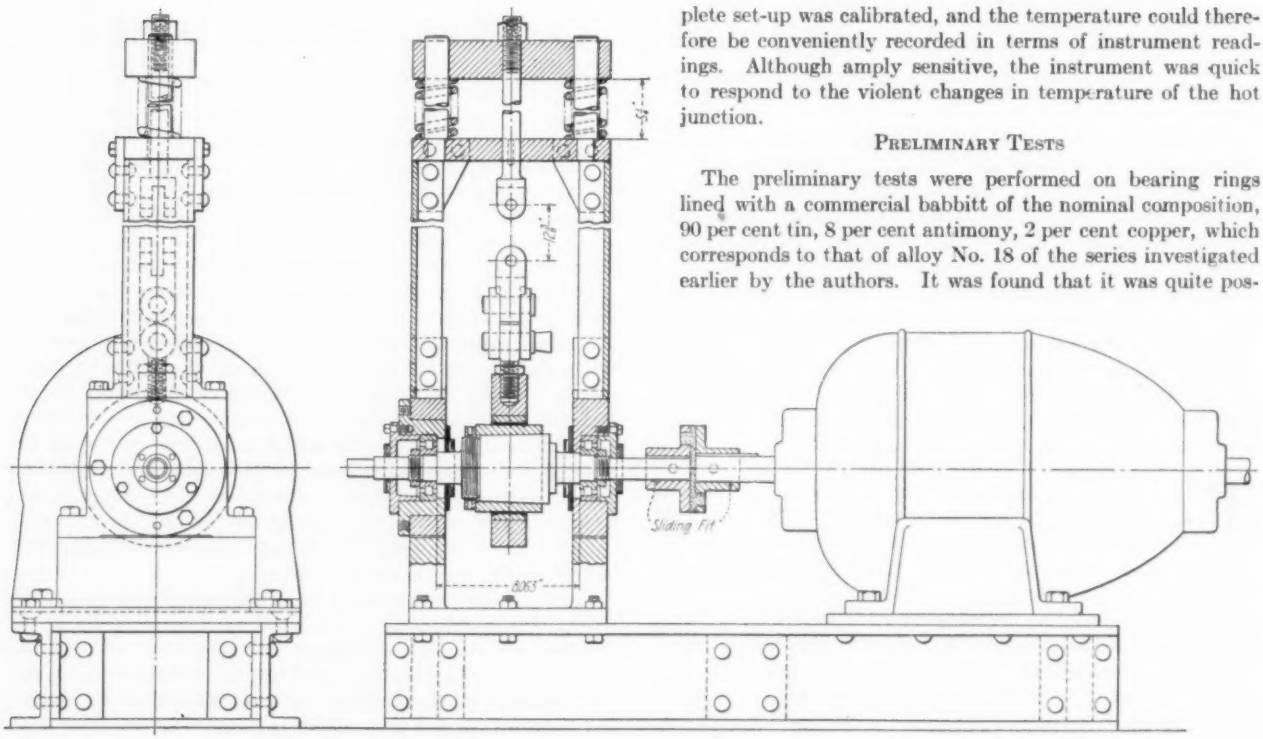


FIG. 1 GENERAL ARRANGEMENT AND DETAILS OF BEARING TESTING MACHINE USED IN TESTS

bearing showed the presence of tin, antimony, and copper in approximately the same proportions as were in the lining, and a considerable amount of iron. "Fibrous material" reported in the oil was due to dust from the air.

With the bearing thus prepared, it was run at 2000 lb. load at 300 r.p.m. until a constant temperature was reached, in the neighborhood of 40 deg. cent. The oil feed was then shut off and the bearing allowed to run further without changing load or speed. After a period of from one to fifteen minutes a sudden increase in friction indicated local seizing with a corresponding increase in temperature. This was measured by a thermocouple which will be discussed later in more detail. The current in the motor field was kept constant during the test, the friction torque being then measured by the armature current. Synchronized readings of torque and temperature were taken every ten seconds and plotted against time. The wide variations observed in the period between the instant when the lubrication was cut off and the first seizure could not be explained by one or another material of the lining, since variations occurred with each material. Apparently it depended on the amount of oil left in the clearance when the needle valve was closed and the condition of the bearing surface. For instance, it was noticed that when linings were run a second time after being once wiped, the bearings could run a considerably longer period without oil. It was not determined whether this was due to oil stored around the thin layer of wiped metal or to the improved bearing surface at the point of wiping.

The thermocouple for measuring the bearing temperature was put in place after the bearing was completely run in, so that it could be located in the close vicinity of journal to lining contact. A copper-constantan couple was used, the cold junction being kept in melting ice, i.e., at 0 deg. cent. The necessity for taking frequent readings during the wiping test proper precluded the use of a potentiometer, and a microammeter of 500 microamperes' range was used in series with the thermocouple. The total resistance of the circuit was approximately 37 ohms. The complete set-up was calibrated, and the temperature could therefore be conveniently recorded in terms of instrument readings. Although amply sensitive, the instrument was quick to respond to the violent changes in temperature of the hot junction.

PRELIMINARY TESTS

The preliminary tests were performed on bearing rings lined with a commercial babbitt of the nominal composition, 90 per cent tin, 8 per cent antimony, 2 per cent copper, which corresponds to that of alloy No. 18 of the series investigated earlier by the authors. It was found that it was quite pos-

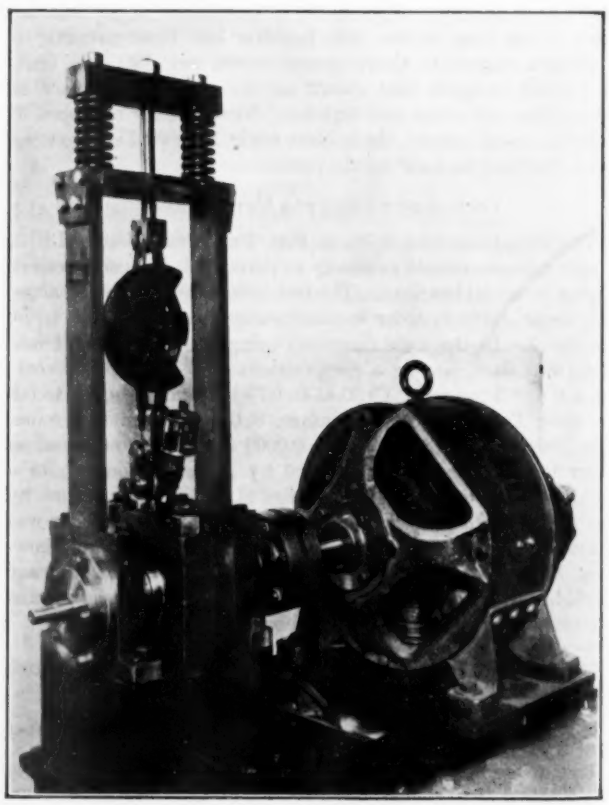


FIG. 2 PHOTOGRAPHIC VIEW OF BEARING TESTING MACHINE SHOWN IN FIG. 1

sible, under the conditions of lubrication described above, to determine the instant of wiping by the sudden increase of friction up to a certain value (800 to 1000 in-lb.). The type of wiping,

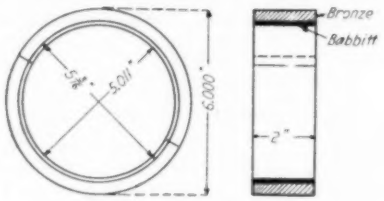


FIG. 3 TEST BEARINGS

common to all failures discussed below, is shown in Fig. 5. The surface layer of metal is seen to be dragged along, forming a thin sheet of babbitt apparently spread over the original surface and fused to it.[5]

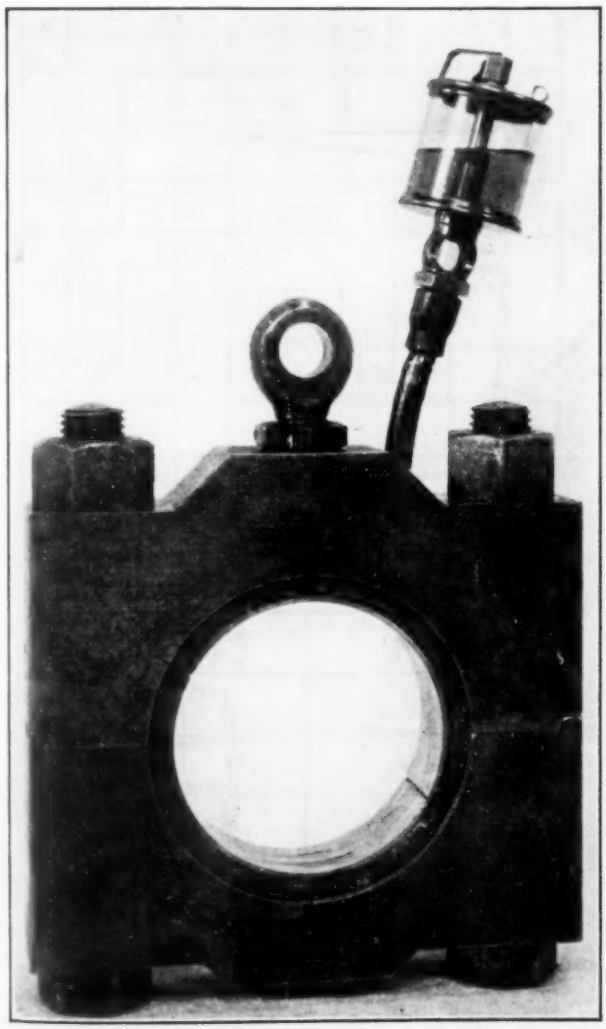


FIG. 4 MOUNTING OF BEARING IN FRAME

The thermocouple used in the earlier tests was placed in the bronze below the babbitt at a distance of approximately 1/16 in. from the rubbing surfaces. Under this condition the temperatures registered when wiping occurred were not higher than 93 deg. cent. and were quite irregular. The change in temperature was not so abrupt as that of torque, and a time lag of the temperature behind the torque was observed. The recorded temperatures in these tests were far below the melting point of the alloys, leading to the belief that a mechanical working of the metal took place. However, when the thermocouple was located nearer the surface of the lining, in the area of actual contact between journal and bearing, higher temperatures were observed. Moreover, a micrographic investigation of the wiped surface did not disclose any signs of cold working, which generally produces a marked orientation of the copper needles in a tin-base babbitt. (For this study copper was deposited electrolytically on the wiped

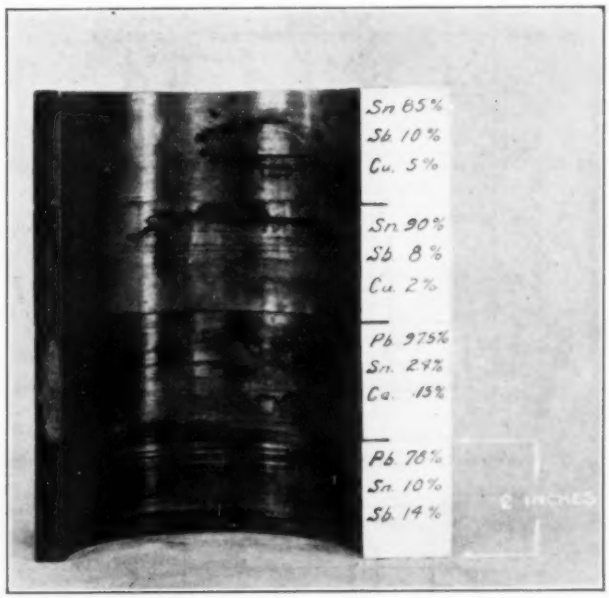


FIG. 5 TYPE OF WIPING EXPERIENCED BY BEARINGS TESTED

portion of the lining and a section across the wiped metal was polished.) An X-ray examination[6] of a tongue of the spread babbitt, which was carefully peeled off, did not show any signs of strain such as might be expected in material mechanically dragged along by the journal.[7] The authors therefore concluded that in

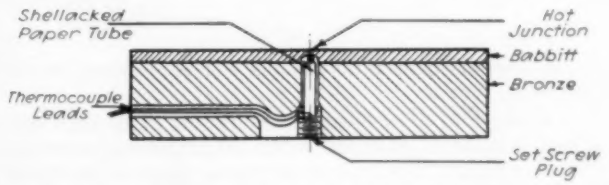


FIG. 6 ARRANGEMENT USED IN MEASURING SKIN TEMPERATURE OF BABBITT LINING

each case the wiped metal must have been melted, and proceeded to obtain a more accurate measurement of the skin temperature of the lining. Fig. 6 shows the arrangement adopted. A very small thermocouple was prepared, the hot junction was mounted in a shellacked paper bushing and the assembly was well cured. The thermocouple was located in a well, drilled to a point within

[5] In most cases a small tongue of metal which could be peeled off the bearing extended beyond the fused portion.

[6] Made by Dr. N. Rashevsky, Research Physicist, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

[7] The authors recognize that annealing of these alloys takes place at room temperature, and that indications of strain might be eliminated on this account.

a few mills of the rubbing surfaces. Positive contact of the junction to the babbitt was obtained by using a small setscrew behind the thermocouple bushing. With this improved thermocouple, sensitive due to its small size, higher skin temperatures were recorded, and the variations of temperature at the area of actual rubbing followed remarkably closely the variations in friction torque. This can be seen in Fig. 7, where a synchronized record of torque and skin temperature is shown for a lining of a special babbitt with a high melting point, which will be discussed further.

Experiments on Wiping

With the improved thermocouple arrangement, linings made of four different bearing metals were tested, following the same procedure as described above. Several linings of each metal were

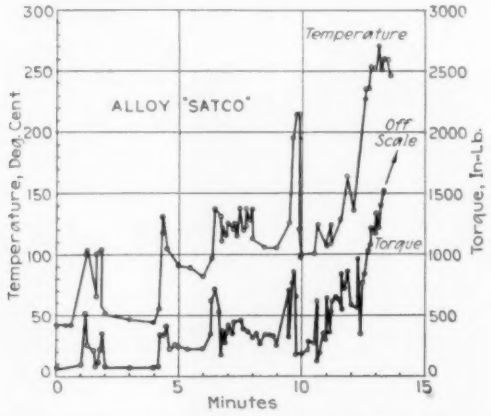


Fig. 7 Synchronized Record of Torque and Skin Temperature

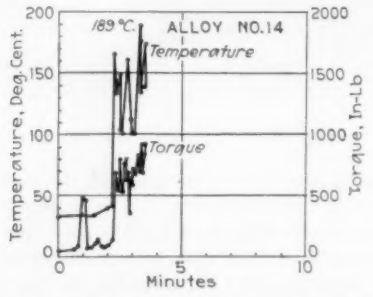


Fig. 8 Typical Record of Friction and Skin Temperature Obtained With a Bearing Lining of No. 14 Alloy

used in order to eliminate the possibility of an occasional error in observation.

(*a*) *Commercial Alloy Westinghouse No. 14.* This alloy has a nominal composition of 85 per cent tin, 10 per cent antimony, and 5 per cent copper. Fig. 8 shows a typical record of the friction and skin temperature in a bearing of this alloy from the instant when the lubrication was cut off until the machine was stopped after gripping occurred. The appearance of this lining can be seen in Fig. 5. It was noticed that the skin temperature at wiping was always between 170 and 180 deg. cent., which was apparently different from the solidus of the alloy or 225 deg. cent. (see p. 15 of the previous paper). However, when a cooling curve was prepared for the lining material, reproduced in Fig. 9, a lower solidus was found—at 180 deg. cent. (see p. 25 of previous paper). This temperature corresponds to the melting point of the lead-tin eutectic; a chemical analysis of the lining actually disclosed the presence of 0.78 per cent of lead. This impurity was the result of tinning the bronze shell prior to pouring the lining, since the shells were tinned with a solder having a composition of Sn, 50 per cent, Pb, 50 per cent.

An interesting check test is shown in Fig. 10. The machine was stopped when lighter gripping and a temperature not higher than 144 deg. cent were reached. When dismantled, the bearing

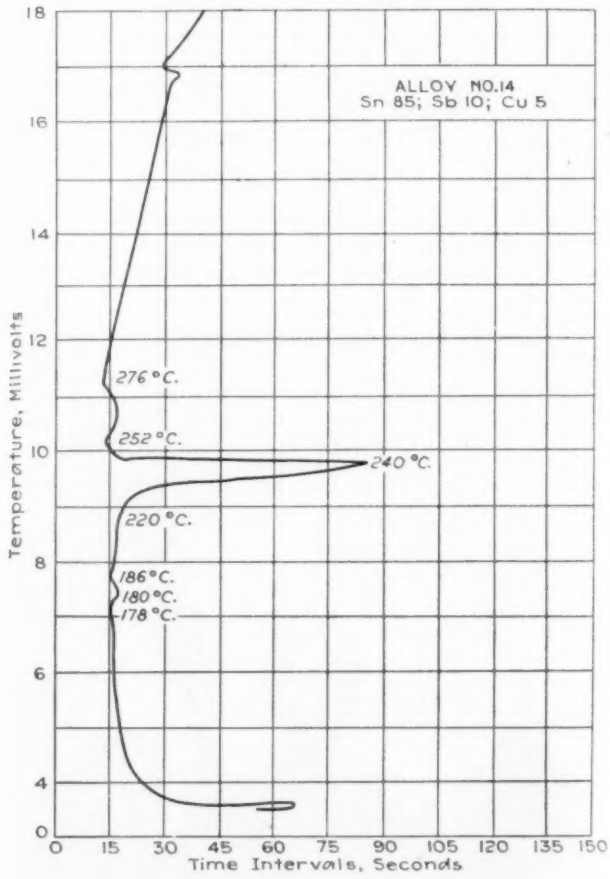


Fig. 9 Cooling Curve for No. 14 Alloy

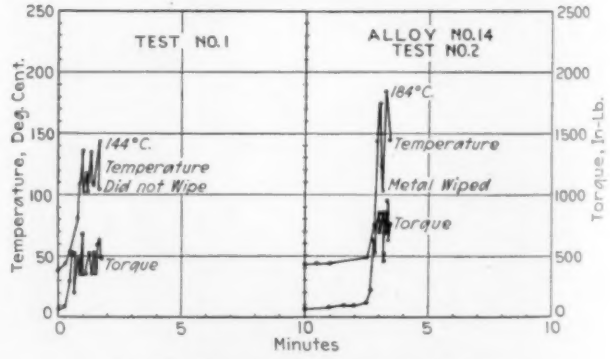


Fig. 10 Check Tests on Alloy No. 14

did not show any signs of wiping. After reassembling the bearing was retested and wiped with a corresponding temperature of 180 deg. cent., approximately.

It was apparent that wiping was a result of the metal reaching its solidus at this temperature. The lead-tin eutectic became liquid and the material "mushy," in which state the upper layer was easily wiped by the journal.

(*b*) *Commercial Alloy Westinghouse No. 60014.* This phe-

nomenon was confirmed when another tin-base alloy was used for a lining. This had nominally 90 per cent tin, 8 per cent antimony, and 2 per cent copper. A typical record of the friction and temperature obtained with a lining of this material is shown in Fig. 11, a photograph of the wiped lining being given in Fig. 5. The wiping again took place at a metal temperature of from 170 to 180 deg. cent., lead being present as a result of the pouring technique. Fig. 12 shows the record of another test made with a lining of alloy No. 60014. This test is of interest because in this case a repeated wiping is easily discernible; one high spot melted away with a resulting drop in friction and in temperature, then a second high spot near-by caught, increased the friction, and melted away. The amount of metal wiped in each case was so small that the molten metal chilled instantaneously. Repeated observations during a number of tests showed that the temperatures of the whole bearing hardly reached 80 deg. cent.

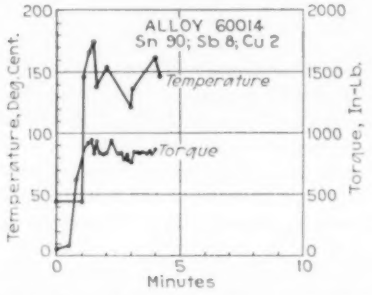


FIG. 11 TYPICAL RECORD OF FRICTION AND SKIN TEMPERATURE OBTAINED WITH A BEARING LINING OF NO. 60014 ALLOY

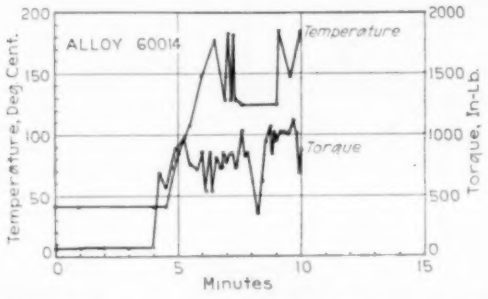


FIG. 12 RECORD OF ANOTHER TEST MADE WITH A LINING OF NO. 60014 ALLOY

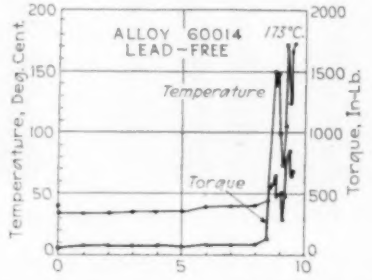


FIG. 13 RECORD OF FRICTION AND TEMPERATURE WHEN SUPPOSEDLY LEAD-FREE LININGS OF NO. 60014 ALLOY WERE WIPED

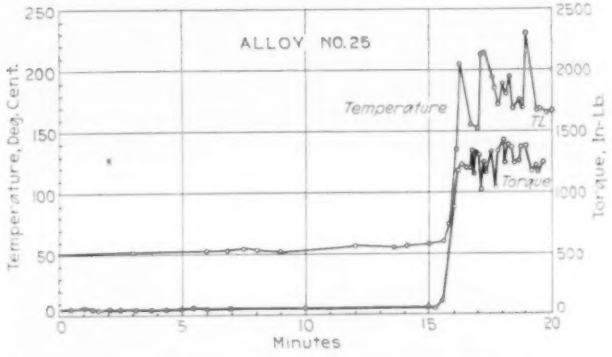


FIG. 14 RECORD OF FRICTION AND SKIN TEMPERATURE FOR BEARING LINED WITH NO. 25 ALLOY

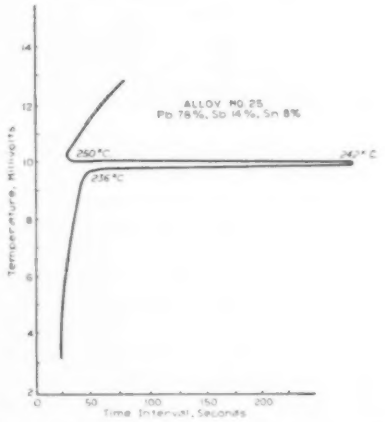


FIG. 15 COOLING CURVE FOR NO. 25 ALLOY

In order to have definite proof that lead in the tinning solder was actually responsible for a wiping temperature lower than the solidus of the Sn 90, Sb 8, Cu 2 alloy, several linings of this metal were prepared using pure tin as a binder between the lining and the shell. Fig. 13 gives the record of the friction and temperature observed when these linings were wiped. Wiping again occurred at 170 to 180 deg. cent. However, a chemical analysis of the lining showed 0.34 per cent of lead present. This came from the commercial

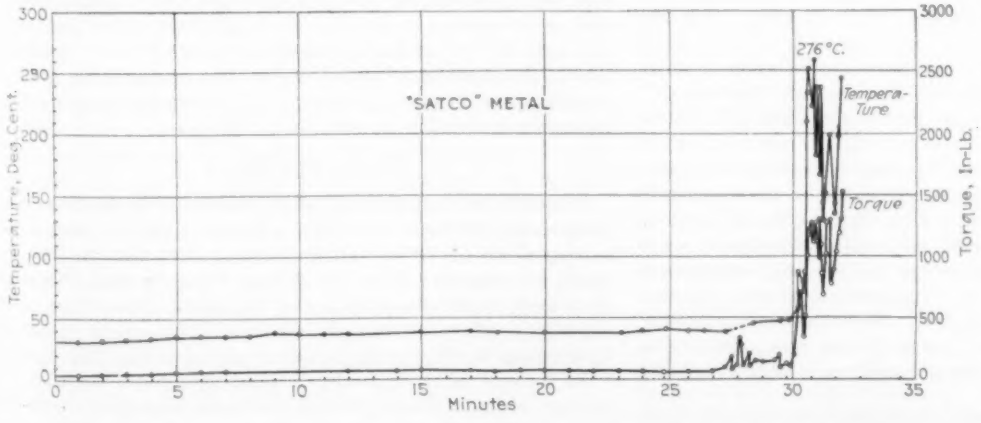


FIG. 16 FRICTION AND TEMPERATURE RECORDS FOR BEARING LINED WITH "SATCO" METAL

tin and antimony used in making the alloy. It was then decided to try alloys quite different from the tin-base babbitts with which this study was particularly concerned.

(*c*) *Commercial Alloy Westinghouse No. 25.* This metal has a nominal composition of 78 per cent lead, 14 per cent antimony, and 8 per cent tin. The same general procedure of testing was followed. One of the wiped bearings lined with the alloy is shown in Fig. 5, while the record of friction and skin temperature for this bearing is given in Fig. 14. The linings wiped at temperatures from 210 to 230 deg. cent. Fig. 15 gives the cooling curve for the No. 25 alloy. The solidus for it is approximately 242 deg. cent., with no lower inversions apparent in the curve. The wider dis-

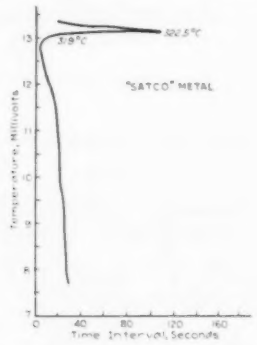


FIG. 17 COOLING CURVE FOR "SATCO" METAL

crepancy between the wiping temperature and the solidus for this metal when compared with the results described above may be easily explained by the fact that the temperatures to be recorded are higher, and the inevitable time lag of the thermocouple is more pronounced.

It is worth while noting the difference in the appearance of the wiped lining in the case of the tin-base and the lead-base metals. The wiping of the latter was found to be appreciably more advanced than with the tin-base metals under the same conditions of testing. It can be explained by the consideration that while in the tin-base babbitts only a minor portion of the babbitt is liquefied at the solidus 180 deg. cent., in the lead-base a considerable fraction of the metal is affected at the temperature 242 deg. cent. Consequently the wiping should be more violent. On the other hand, the mechanical strength of lead-base babbitt at 240 deg. cent. is considerably lower than that of tin-base metal at 180 deg. cent., which is probably the cause of the scored and grooved appearance of the wiped lead-base linings.

This holds true also for the next metal tested, namely,

(*d*) *"Satco" Metal.* This metal was submitted by Mr. C. T. Ripley of the Atchinson, Topeka & Santa Fe Railway. It is one of the metals recently developed containing up to 98 per cent of lead, the necessary strength being secured by addition of small percentages of alkali earth metals. The German "Bahnmetall" is of the same nature. The chemical composition of the submitted sample of Satco was found to be: 97.5 per cent lead, 2.4 per cent tin, 0.15 per cent calcium, 0.07 per cent potassium, and traces of aluminum, barium, magnesium, and sodium. Its strength is approximately the same as that of the 90 Sn, 8 Sb, 2 Cu alloy. A photograph of one of the bearings lined with this material is given in Fig. 5, the corresponding friction and temperature records being shown in Fig. 16. The skin temperature recorded at wiping was 270 to 290 deg. cent. Fig. 17 shows the cooling curve for this metal.[8] The solidus is 320 deg. cent., and no discontinuities in the cooling curve at lower temperatures could be found. The discrepancy between wiping temperature and solidus was caused probably by the time lag of the thermocouple.

The length of the time between the stoppage of lubrication and wiping (30 min.) is accidental. Other linings of the same material wiped shortly after the needle valve was closed. As mentioned before, this time depended mostly on the condition of the bearing surface.

DISCUSSION OF RESULTS

In the authors' estimation the reported series of tests, of which typical examples were shown above, proves quite definitely that rise of temperature right at the journal is essential for wiping. It appears that in so far as tin-base babbitts are concerned, the unavoidable lead content in commercial tin and antimony causes all metals of this type to wipe at the same temperature of 180 deg. cent. However, this wiping is only slight and generally

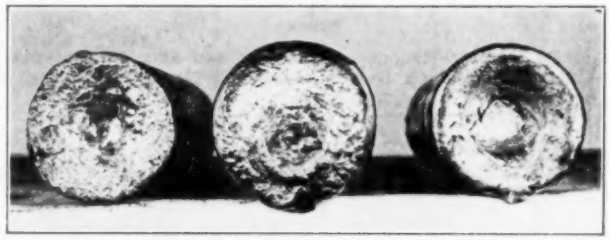


FIG. 18 TOP VIEW OF INGOTS CAST FROM TIN-BASE BABBITTS

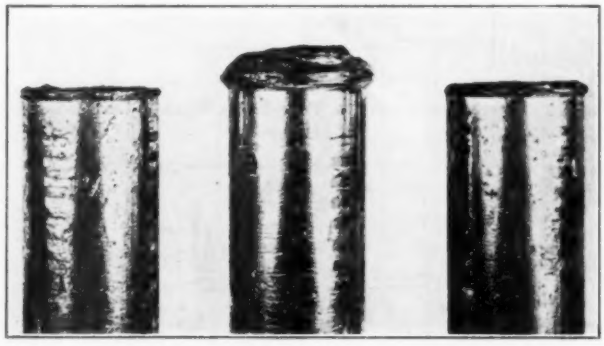


FIG. 19 SIDE VIEW OF INGOTS CAST FROM TIN-BASE BABBITTS

does not exclude the possibility of subsequent successful service of the bearing, provided the conditions which led to the wiping are eliminated (lack of lubrication, misalignment, etc.). A tin-base babbitt should therefore be selected for a particular application on the basis of its mechanical strength and ease of pouring. The authors are therefore augmenting the data given in the first part of the study by recording further observations made during the casting of the various alloys of this series and data on the resistance of the alloys to plastic deformation.

CASTING PHENOMENA

When the castings of the 25 alloys referred to in the first part of this study were set up in order, it was noted that all those containing about ½ per cent of copper, no matter what their antimony content, were characterized by a relatively deep pipe and by a lustrous surface at the top of the ingot. The surface was crinkled, but free from any granulation. There was no evidence of shrinkage cracks (see the left-hand casting of Fig. 18).

In the case of those castings containing about 1 per cent of copper, the upper surface protruded from the mold (see the middle casting of Fig. 19). The surface was lustrous but was character-

[8] Prepared by Dr. F. R. Hensel, Research Metallurgist, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

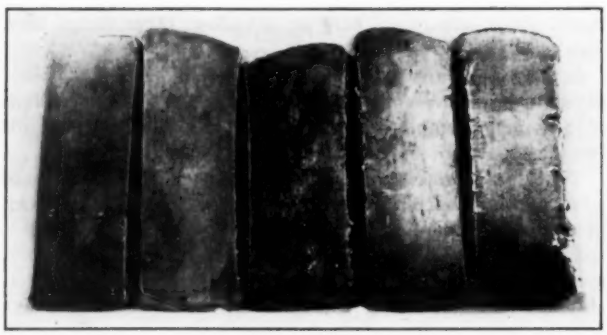


Fig. 20—Samples 1–5

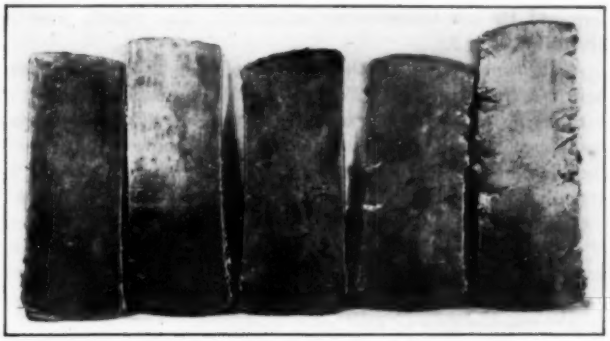


Fig. 22—Samples 11–15

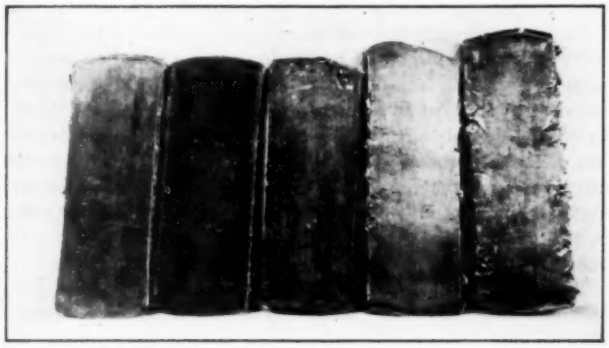


Fig. 21—Samples 6–10

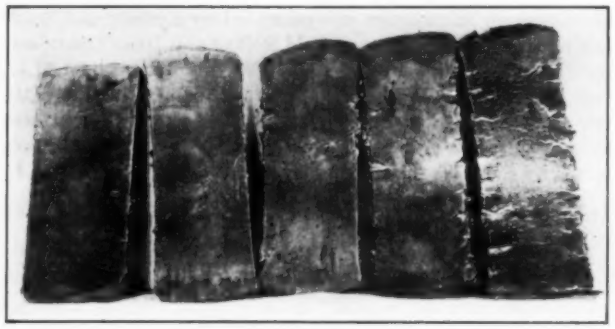


Fig. 23—Samples 16–20

ized by numerous excrescences. These swellings were filled with gas expelled from the alloy during its solidification.

Those castings containing 2, 4, and 8 per cent of copper, respectively, no matter what their content of antimony, were also characterized by a pipe, but this pipe was relatively shallow and at its apex was, in most cases, marked by a shrinkage crack (see the right-hand casting in Fig. 19). The surfaces of the castings were less lustrous than those of the castings already described, this lack of luster being due in large measure to granulation of the surfaces occasioned, no doubt, by the presence of crystals of the tin-copper compound, CuSn.



Fig. 24—Samples 21–25

FIGS. 20–24 APPEARANCE OF SAMPLES AT CONCLUSION OF ROLLING OPERATIONS

The peculiar character of the castings containing about 1 per cent of copper appears to the authors to be due to the conditions of freezing of these alloys. In the case of those alloys containing either less and more than 1 per cent of copper, freezing is in progress over a range of temperature, and during the time that the alloy is in process of solidification, gases present in the alloy can escape without hindrance. In the case of the alloys containing about 1 per cent of copper, the freezing range is relatively narrow and solidification of the metal in the mold is rapid. The gases escaping from the casting are thus entrapped in the upper part of the mold and make their presence evident by the formation of blowholes and bubbles near or in the upper surface of the casting.

THE EFFECT OF COLD WORK

A number of references to the effect of cold work on alloys of this type have appeared during the past few years. Thompson and Orme (*Jl. Inst. Met.*, vol. 22 (1919), p. 203), for example, remark that the rolling of Britannia metal "presents very little difficulty. An ingot $^3/_4$ in. thick can be reduced to $^1/_{16}$ in. in about a dozen passes, which treatment results in little or no hardening." No specific alloy is referred to in their remarks. Greaves (*Jl. Inst. Met.*, vol. 22 (1919), p. 213), in discussing their paper, showed that rolling progressively softened these alloys but that "aging" tended to restore their hardness. His tests were made on three alloys of the following compositions, cast in warm molds into ingots $1^1/_2$ in. square.

Ingot number	1	2	3
Copper, per cent	nil	0.81	1.5
Antimony, per cent		5.0 to 5.5	

Hardness tests were made with a 10-mm. ball under a load of 500 kg. for one minute. The ingots were rolled to 0.8 in. thick and hardness tests again made on the surface, and the alloy was found in each case to be softer. Rolling was continued without annealing to 0.6 in. thick and a further set of hardness tests made,

TABLE 2 EFFECT OF COLD WORK ON HARDNESS OF BRITANNIA METAL (DIAMETER OF IMPRESSION IN MM.)

Ingot number	1	2	3
As cast	6.29	5.64	5.23
Rolled to 0.8 in., 20 min. after rolling	7.03	5.85	5.99
Rolled to 0.6 in.; 20 min. after rolling	7.40	6.70	7.04
Rolled to 0.6 in.; three days after rolling	..	6.68	6.90
Rolled to 0.6 in.; after 1 hr. at 100 deg. cent	7.24	6.47	6.64
Rolled to 0.6 in.; after 1 hr. at 200 deg. cent	6.37	5.87	5.75

followed by low-temperature annealing. The results were as given in Table 2.

At the same meeting of the Institute of Metals, Fry and Rosenhain (*Jl. Inst. Met.*, vol. 22 (1919), p. 219) discussed the effect of hammering on the hardness and structure of a typical bearing metal cast under a variety of conditions and showed very clearly that hammering softened the alloy, while hammering followed by annealing at 100 deg. cent. for 16 hours resulted in quite appreciable softening. Fry and Rosenhain also showed the importance of structure upon the resistance of these alloys to deformation, noting that the fine-grained ingots stood the hammering comparatively well, whereas the coarse-grained samples cracked and broke after but a small amount of hammering.

At the Philadelphia (October, 1928) meeting of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers, a considerable contribution to our knowledge on this subject was presented by Egeberg and Smith in a paper entitled, "Effect of Cold Rolling and Heat Treatments on Physical Properties of Britannia Metal" (Trans. A.I.M.E., Inst. Metals Div., 1929, p. 373). The approximate analysis of the materials investigated by them was 91 per cent tin, 7 per cent antimony, and 2 per cent copper. The results which were obtained by them are shown in Table 3.

TABLE 3 EFFECT OF HAMMERING ON HARDNESS OF TIN-BASE BABBITT

	Initial state	After boiling in water 30 min.	After heating at 300 deg. fahr. 90 min.	After heating at 400 deg. fahr. 45 min.	After heating at 440 deg. fahr. 30 min.
	Brinell hardness				
3/4 in. cast condition	23.8	22.8	22.8	22.8	22.8
Cold rolled to 3/8 in. in four passes	19.7	20.1	19.3	19.7	20.9
Cold rolled to 1/4 in. in two more passes	18.6	18.2	17.8	20.1	20.9
Cold rolled to 3/16 in. in one more pass	17.2	17.2	18.6	20.1	20.9
Cold rolled to 1/8 in. in one more pass	15.9	16.8	17.8	20.1	20.5
Cold rolled to 1/16 in. in three more passes	13.3	14.8	17.2	18.6	19.3
Cold rolled to 1/32 in.	[a]	[a]	[a]	[a]	[a]

[a] Too thin for Brinell test.

Here again confirmation of the softening effect of cold work on these high-tin alloys was obtained. The further interesting fact was elicited in the discussion of this paper by one of the present authors (O. W. E.) that the hardening of these alloys due to heating after cold rolling (cf. Table 2) is a characteristic only of material which has been highly deformed—in the case of the 91 per cent tin, 7 per cent antimony, and 2 per cent copper alloy reduced one-half to two-thirds or more in thickness by cold rolling. When the amount of deformation is less than about 50 per cent, then further softening occurs on annealing, other things being equal.

TABLE 4 NOMINAL COMPOSITIONS OF ALLOYS TESTED IN ROLLING EXPERIMENTS

Alloy no.	Nominal composition Sn	Sb	Cu
1	97.5	2	0.5
2	97	2	1
3	96	2	2
4	94	2	4
5	90	2	8
6	95.5	4	0.5
7	95	4	1
8	94	4	2
9	92	4	4
10	88	4	8
11	93.5	6	0.5
12	93	6	1
13	92	6	2
14	90	6	4
15	86	6	8
16	91.5	8	0.5
17	91	8	1
18	90	8	2
19	88	8	4
20	84	8	8
21	89.5	10	0.5
22	89	10	1
23	88	10	2
24	86	10	4
25	82	10	8

In the present investigation the effect of cold work on 25 alloys of the tin–antimony–copper system has been studied. The alloys' of the nominal compositions given in Table 4, were machined into test pieces, 1 1/2 in. long, 1 in. wide, and 1/2 in. thick.

The initial hardness of each sample, as machined, was taken on a baby Brinell machine, using a 1/16-in. ball. But the variation in the size of the impressions was so small that it was decided to use an 1/8-in. ball and no load in the lever arm on the Rockwell machine. The results obtained on the Rockwell tester are probably not very accurate as to the absolute hardness of the alloys, but they show the general trend of the effects of cold rolling quite well. After each pass through the rolls the samples were allowed to stand about four hours before testing in order to make sure they were always tested at room temperatures.

Each pass through the rolls caused a reduction of 5 per cent or 0.025 in. The depth of the impression of the 1/8-in. ball was calculated to be 1/64 in., and it was assumed the alloys could be rolled to twelve times the depth of the impression, or 3/16 in., without noticeably affecting the results. On this assumption the test pieces were rolled to 0.175 in. Every sample was given the full reduction on each pass, no attempt being made to stop cracking by trimming the samples after rolling. All pieces were rolled to the finished size except one (No. 25), which broke up completely on the twelfth pass.

Table 5 gives data as to the compositions of the alloys, their hardness before and after rolling, and the condition of the samples after rolling.

TABLE 5 INITIAL AND FINAL HARDNESS OF ROLLED BABBITTS

Sample no.	Per cent Cu	Per cent Sb	Hardness before rolling	Hardness after rolling	Condition after rolling
1	0.5	2	0.7	10.0	No cracks
2	0.5	4	7.9	—0.7	No cracks
3	0.5	6	18.8	—5.0	No cracks
4	0.5	8	25.8	0.0	Small cracks
5	0.5	10	40.0	4.0	Few large cracks
6	1	2	15.0	8.0	No cracks
7	1	4	25.5	19.8	No cracks
8	1	6	33.9	10.0	No cracks
9	1	8	40.5	14.5	Few large cracks
10	1	10	52.1	9.0	Few large cracks
11	2	2	32.7	26.2	No cracks
12	2	4	39.2	12.7	No cracks
13	2	6	44.4	9.7	No cracks
14	2	8	49.8	17.8	Few large cracks
15	2	10	61.9	18.0	Large deep cracks
16	4	2	46.8	23.3	No cracks
17	4	4	49.0	18.0	No cracks
18	4	6	55.6	13.0	Small cracks
19	4	8	57.1	12.0	Large cracks
20	4	10	63.9	15.0	Large cracks
21	8	2	51.0	17.5	Very few cracks
22	8	4	50.0	15.0	Very few cracks
23	8	6	51.6	14.7	Few large cracks
24	8	8	58.2	12.5	Large deep cracks
25	8	10	68.7	—9.0 [a]	Broken

[a] No. 25 completely broken on twelfth pass. Hardness after eleventh pass is quoted.

Figs. 20 to 24 show the appearance of the samples at the conclusion of the rolling operations. The rectangular section missing in the 10 per cent antimony sample of Fig. 24 was used as a specimen for microscopic examination (see below).

The hardness numbers observed at the conclusion of each of the passes are given in Table 6.

The values given in Table 5 have been used in the preparation of the curves shown in Figs. 25, 26, 27, 28, and 29. A study of these curves elicits two outstanding facts:

1 That, no matter what their content of copper, the alloys of low antimony content increase in hardness during the first stages of reduction, later decreasing in hardness as deformation is continued. In this connection it is of interest to note that the initially soft alloys retain their hardness with increasing deforma-

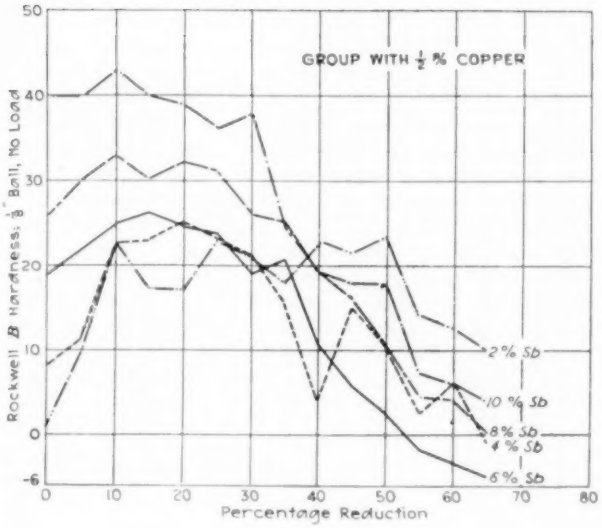


Fig. 25

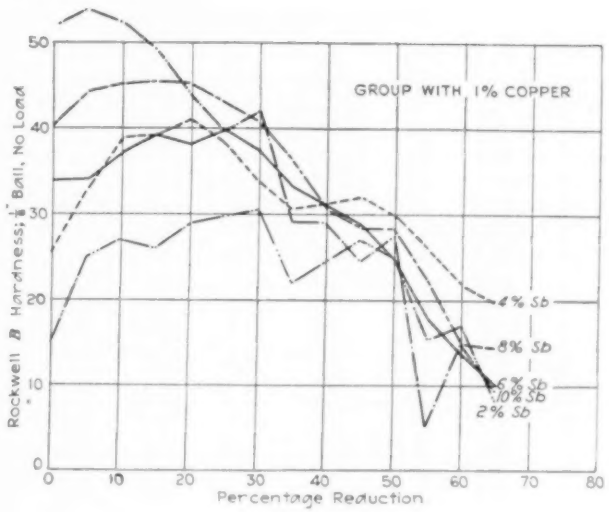


Fig. 26

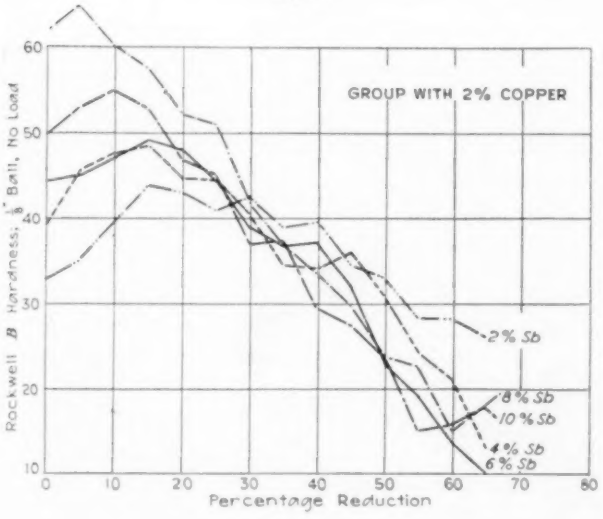


Fig. 27

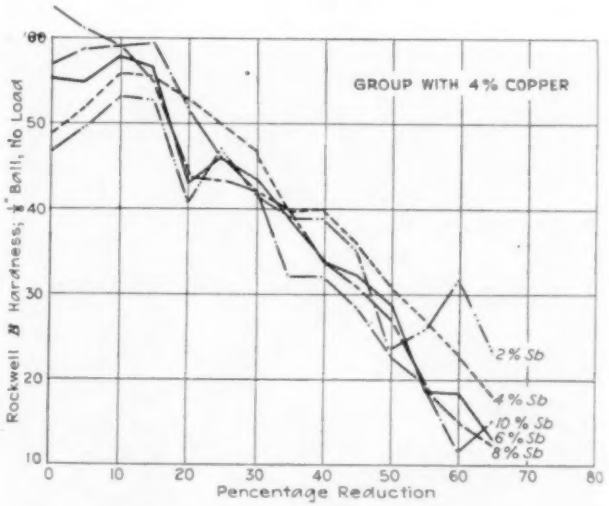


Fig. 28

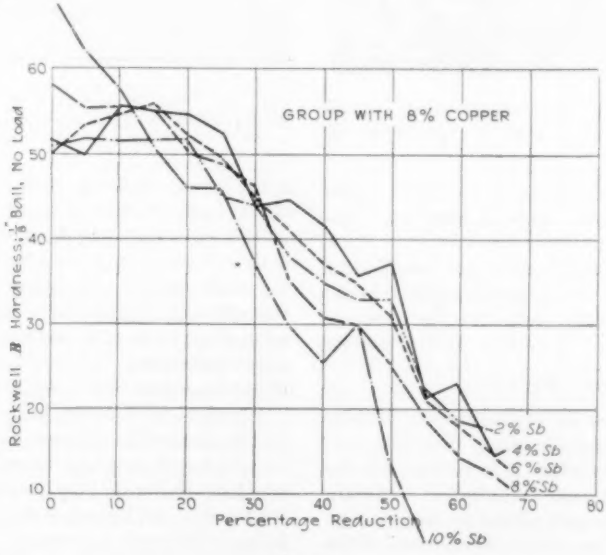


Fig. 29

FIGS. 25–29 VARIATION OF HARDNESS OF ALLOYS DURING ROLLING PROCESS

TABLE 6 RESULTS OF HARDNESS TESTS MADE SUBSEQUENT TO EACH PASS IN ROLLING

(Rockwell "B" Hardness,[1] 1/8-in. ball, no load in lever arm)

No.	As machined, 0.500 in.	1st pass, 0.475 in.	2nd pass, 0.450 in.	3rd pass, 0.425 in.	4th pass, 0.400 in.	5th pass, 0.375 in.	6th pass, 0.350 in.	7th pass, 0.325 in.	8th pass, 0.300 in.	9th pass, 0.275 in.	10th pass, 0.250 in.	11th pass, 0.225 in.	12th pass, 0.200 in.	13th pass, 0.175 in.
1	0.7	9.7	22.3	17.3	16.9	22.7	20.8	17.8	22.8	21.5	23.5	14.2	12.5	10.0
2	7.9	11.1	22.7	23.0	24.9	22.7	21.1	15.5	4.0	15.2	10.3	2.5	6.0	−0.7
3	18.8	21.8	24.7	27.2	26.0	24.4	22.7	19.1	20.5	10.3	5.8	2.3	−1.2	−5.0
4	25.8	30.1	33.0	30.2	32.2	31.0	26.0	25.1	19.0	16.2	10.5	4.6	4.3	0.0
5	40.0	39.9	43.2	40.2	38.8	36.2	31.9	24.6	19.0	17.6	17.8	7.0	6.0	4.0
6	15.0	25.2	27.0	26.0	29.2	29.8	30.4	21.9	24.5	27.2	24.8	15.4	16.7	8.0
7	25.5	32.7	39.1	39.4	40.9	38.4	33.9	30.6	31.3	32.2	30.0	26.0	21.5	19.8
8	33.9	34.0	37.0	39.3	38.1	39.9	37.4	33.2	30.8	28.8	24.8	18.0	13.7	10.0
9	40.5	44.5	45.3	45.7	45.4	43.0	41.1	36.3	30.3	28.6	28.5	22.3	14.8	14.5
10	52.1	54.1	52.3	49.0	43.9	39.7	42.2	29.0	29.1	24.6	27.8	5.0	15.2	9.0
11	32.7	35.0	39.8	44.1	42.8	41.3	42.5	38.9	39.6	34.5	33.2	28.3	28.2	26.2
12	39.2	45.7	47.6	48.8	44.6	44.5	40.5	34.3	34.0	36.0	31.0	24.6	20.9	12.7
13	44.4	44.8	47.7	49.3	48.0	44.4	39.1	36.8	37.3	32.0	23.1	19.6	13.8	9.7
14	49.8	53.1	55.3	52.8	46.9[a]	44.8	37.2	37.8	29.7	27.6	23.8	15.0	15.8	17.8
15	61.9	63.3	60.3	57.8	52.2[a]	49.2	41.8	36.6	33.7	29.4	23.9	22.4	15.0	18.0
16	46.8	49.8	53.5	53.0	40.8	47.1	41.8	39.0	38.9	35.1	23.5	25.8	31.8	23.2
17	49.0	52.1	56.0	55.7	52.9	47.2	47.0	39.8	40.0	36.0	30.8	27.2	22.7	18.0
18	55.6	54.9	58.1	56.7	42.8	46.0	43.9	38.9	33.8	32.2	28.6	18.6	18.2	13.0
19	57.1	58.9	59.1	55.2	44.1[b]	43.7	42.2	39.7	33.8	31.2	27.2	19.2	15.0	12.0
20	63.9	60.8	59.1	59.4	52.1[b]	46.1	42.1	32.2	32.2	28.6	22.8	19.6	11.8	15.0
21	51.0	51.9	51.7	51.8	51.8	45.2	44.2	38.0	35.0	33.2	33.2	23.0	18.6	17.5
22	50.0	53.5	54.8	56.1	52.2	49.8	44.8	40.7	37.1	34.8	31.0	20.7	18.0	15.0
23	51.6	50.0	55.8	55.2	54.7	52.7	44.0	44.7	41.9	35.8	37.2	21.5	23.0	14.7
24	58.2	55.5	55.8	55.2	50.5[b]	49.2	46.0	35.3	31.0	30.0	25.3	19.0	14.3	12.5
25	68.7	62.0	57.7[a]	50.2	46.1[b]	45.8	36.9[c]	29.9[c]	25.4	30.0	14.1	−9.0	[d]	[d]

[a] Definite signs of cracking.
[b] Definite signs of breaking up.
[c] The following are arranged in order of size of cracks after the 6th pass, No. 25 having the largest: 25, 20, 15, 10, 19, 14, 24, 5.
[d] No. 25 completely broken on 12th pass.

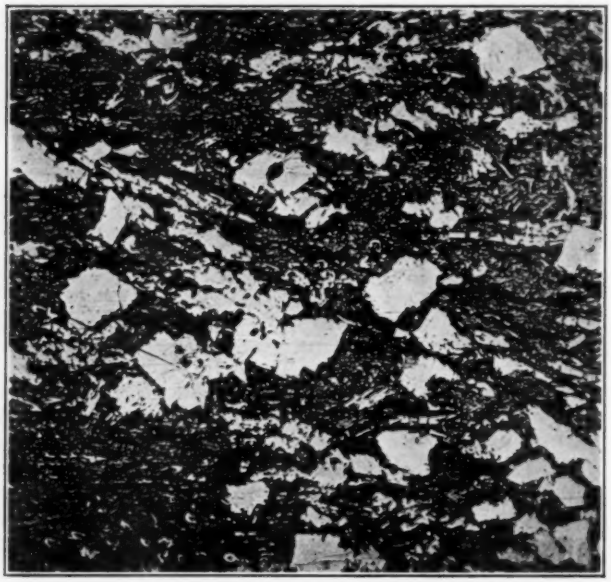


FIG. 30 MICROSTRUCTURE OF SAMPLE CUT FROM ALLOY NO. 25 AFTER HAVING BEEN REDUCED 65 PER CENT IN THICKNESS BY ROLLING. MAGNIFICATION 150×

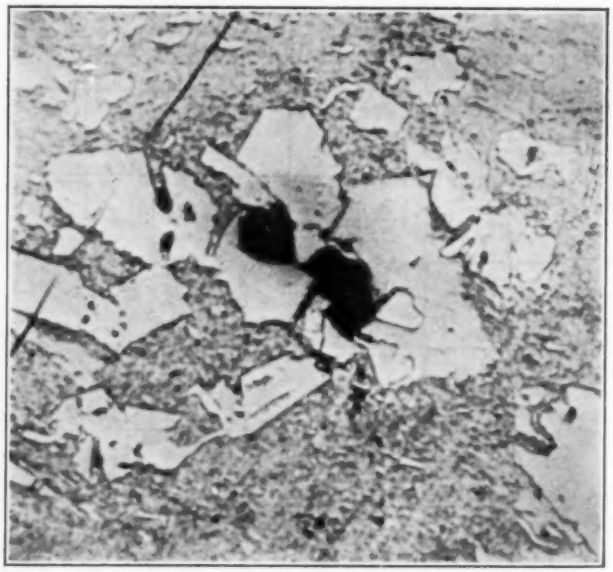


FIG. 31 PHOTOMICROGRAPH OF UNETCHED SECTION OF SAMPLE ILLUSTRATED IN FIG. 30, SHOWING EVIDENCE OF FORMATION OF CAVITIES

tion more completely than the initially hard, so that after reduction to 0.175 in. the initially soft alloys have in many cases become harder than the initially hard.

2 That, no matter what their content of copper, the alloys of high antimony content (8 per cent and 10 per cent) *tend* to decrease in hardness continuously as they are reduced in thickness by rolling.

MICROSTRUCTURE—DENSITY

The effect of plastic deformation on the microstructure of these alloys has been referred to by Fry and Rosenhain (loc. cit.), who have shown that hammering had the effect of breaking both the cubes of tin-antimony compound and the needles of CuSn. Rolling has much the same effect as hammering, as may be seen by reference to Fig. 30, which shows the microstructure of the sample cut from alloy No. 25 after it had been reduced 65 per cent in thickness by rolling. It is of interest also to note the tendency of the CuSn needles to orient themselves in the direction of rolling. In this photomicrograph, evidence of the formation of cavities, both in the matrix of the alloy and within the shattered cubes of the tin-antimony compound, is forthcoming. Confirmation of this effect of deformation is given in Fig. 31, which is a photomicrograph of an unetched section of this alloy at a magnification of 500 diameters. The cavities in the vicinity of a shattered cube of SnSb are very clearly defined in this section.

Whether the decrease in hardness occasioned by deformation can be ascribed in all cases to the disruption of the structure is open to question in view of the experience of Egeberg and Smith, who have shown that the annealing of cold-rolled Britannia metal (91 per cent Sn, 7 per cent Sb, 2 per cent Cu) causes it to increase in hardness quite appreciably, though, be it noted, never to recover its original resistance to deformation. The authors are of

the opinion that at least some of the loss in hardness can be ascribed to the formation of cavities within the material, particularly in the case of such material as contains cubes of the tin-antimony constituent.

Confirmation of the formation of cavities within the material is obtained from density measurement. The fact that deformation reduces the density of these alloys has been referred to by Thompson and Orme (loc. cit.) in their reply to the discussion of their paper. They quote Dr. Carl Kamarsh as having shown that rolling lowers the specific gravity of Britannia metal from 7.361 to 7.339. The authors' experiments on this phase of the subject were made on two pieces (numbered 1 and 2) $^1/_2$ in. thick and about 1 in. square, taken from an alloy containing approximately 94 per cent tin and 6 per cent antimony. The specific gravity of these was found to be 7.402 and 7.405, respectively, thus showing that the method used for the determination of specific gravity was correct to a small integer in the third decimal place. The pieces were then rolled to the same thickness as the other samples, namely, 0.175 in. Piece No. 2 was taken down in regular steps of 0.025 in. per pass. No attempt was made to regulate the number of passes to which No. 1 was subjected, it being merely used as a gage for No. 2. In all probability No. 1 received three times as many passes as No. 2, and the average reduction per pass was one-third that of No. 2. When the specific gravity was again taken, No. 1 was found to have decreased from 7.405 to 7.053, and No. 2 from 7.402 to 7.092.

Constitution of the Tin-Antimony-Copper System

In both of the authors' papers the cube- and needle-shaped constituents of these alloys have been referred to as SnSb and CuSn, respectively. In referring to these constituents in this way they have followed the lead of Campbell (Proc. Am. Soc. Test. Matls., vol. 13 (1913), p. 630) and of Bonzack (*Zeit. für Metallkunde*, vol. 19 (1927), p. 109), who are in apparent agreement as to the nature of these phases. The authors, while admitting the likelihood that in these alloys as cast the cubes are essentially of the compound SnSb, are not prepared to accept without comment the view that the needles are of the compound CuSn, seeing that the existence of this compound has still to be confirmed.

Both Shepherd and Blough (*Jl. Phys. Chem.*, vol. 10 (1906), p. 630) and Haughton (*Jl. Inst. Met.*, vol. 25 (1921), p. 309) offer proof that these needle-shaped crystallites consist of a solid solution of variable composition to which they have applied the symbol ϵ (epsilon). Nevertheless, while the authors are of opinion that the experimental methods adopted by Shepherd and Blough and by Haughton in their investigation of the copper–tin system are on the whole superior to those used by Ishiwara (*Jl. Inst. Met.*, vol. 31 (1924), p. 315), the latter's opinion that the epsilon constituent is the compound CuSn cannot be lightly dismissed, particularly when the cast alloys of this system are under consideration. In brief, the authors believe that the needles in these alloys as cast are of the compound CuSn, but in these alloys in a state of equilibrium are of a solid solution (ϵ).

Discussion

E. I. Larsen.[9] It may be interesting to note the effect of aging on the cold-rolled metals referred to in this paper. Subsequent to rolling, the pieces were aged for two months at room temperature (approximately 24 deg. cent.), after which hardness measurements were made. The pieces were then given an accelerated aging in boiling water (97 deg. cent.), and the hardness was again measured. Following the aforementioned treatment, the samples were further aged at room temperature for a period of six months before again measuring the hardness. Curves were drawn similar to those of the authors in which the antimony percentages in the various copper groups were plotted against hardness. The variations in hardness were found to be fairly small, the maximum change being approximately 20 points (Rockwell B hardness scale, $^1/_8$-in. ball, no load) or about 30 per cent of the total change due to rolling. The maximum change occurred during the two months after rolling. The hardness of the alloys containing 4 and 8 per cent of copper increased, while the hardness of those containing less than 4 per cent decreased.

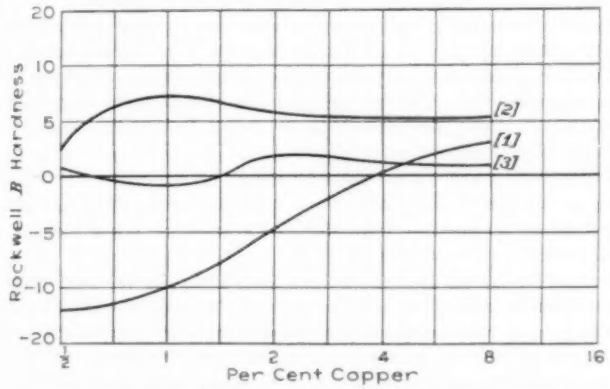


Fig. 32 Change of Hardness During Aging Periods
(Aged [1] for two months at room temperatures; then [2] for eight hours at 95 to 100 deg. cent.; then [3] for six months at room temperature.)

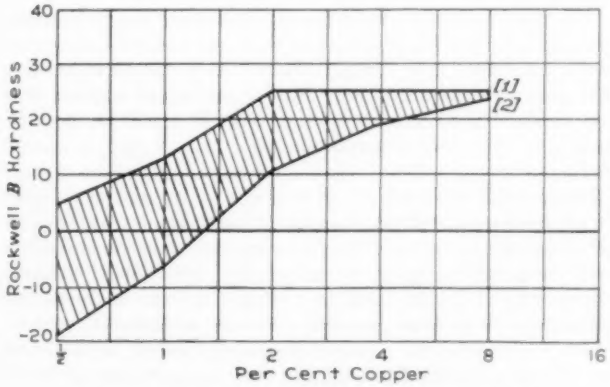


Fig. 33 Hardness Range in Groups After Aging
(Top curve [1], maximum hardness; bottom curve [2], minimum hardness.)

Now if the curves of each copper group are averaged, it will be noted that in the case of the alloys containing less than 4 per cent copper the change in hardness resulting from aging for two months at room temperature is inversely proportional to the copper content; while for alloys containing 4 per cent or more of copper the change in hardness is directly proportional to the copper content. (See curve 1, Fig. 32.) All the alloys became slightly harder during the eight hours' aging in boiling water. (See curve 2, Fig. 32.) The subsequent aging for six months produced little change in the various groups. (See curve 3, Fig. 32.) It was noted, however, that after the aging treatment the hardness of the several alloys in the group containing 0.5 per cent copper varied over a range of 25 Rockwell B points; whereas if the copper content is increased to 8 per cent, the range of hardness has decreased to approximately two Rockwell B points. (See Fig. 33.)

The foregoing results may be of little practical value, but they are most interesting from a theoretical point of view. These data seem to indicate that copper is the major factor in promot-

[9] Research Laboratory, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

ing age-hardening in alloys of this type. However, further work is necessary before definite conclusions can be drawn.

H. A. S. HOWARTH.[10] This contribution on tin-base bearing metals is an important addition to the literature on the nature and causes of bearing failures. Although the authors now discuss their failure in the absence of a lubricant, it is hoped that they will continue their study further and show the nature of failures that occur in the presence of lubricants. The oil may be overloaded with gritty matter or it may be used in the presence of electric potential difference between the bearing surfaces.

The writer is glad to have the suggestion that the presence of so small an amount of lead as 0.34 per cent in a tin-base babbitt makes it sensitive to overheating and more liable to failure in the absence of oil. Occasionally the question of lead contamination arises in the purchase of babbitt metal, bought by this company in large quantities on specification.

Prevention of contamination of babbitt in the shop is assisted by use of babbitt for tinning the bearing surfaces and by the use of babbitt heads on soft hammers. Lead is kept out of this factory as far as practicable.

An examination of Figs. 25 to 29 leads one to the conclusion that peening would be less harmful for compositions whose hardness is least changed thereby if the peening were done merely to tighten the hold of the anchors. If, however, peening is resorted to for hardening the surface, the composition must be chosen accordingly. However, this company disapproves of peening and uses a composition that lies between those illustrated by Figs. 28 and 29. This practice therefore appears rational.

From the authors' remarks about "running in" the journal and bearing before testing, it is evident that they realize the influence of journal finish upon bearing failure. It would be interesting if they would follow this phase further and report whether they can obtain a journal material and finish that will be most reluctant to seize the bearing metal.

The writer once tried to produce seizure by pressing a small block of babbitt, held in a tool post of a boring mill, against the finished surface of a thrust-bearing runner made of cast iron, but could not get them to seize. This was only a crude and unrecorded experiment, but it led to the belief that "finish" was very important and that persistence of change in shape of the runner surface due to operating temperatures was a factor not to be overlooked. Hence, tests should be conducted with models that adequately resemble the bearings to the improvement of which the test results are to be applied.

For the foregoing reason it is believed that the authors should have used a shaft whose journal would not trap the heat so readily. A sleeve, when used as a journal, will heat and expand away from the shaft. As soon as this separation takes place the heat is trapped and the sleeve will expand rapidly and may bring about failure sooner than it would have occurred if the journal had been integral with the shaft. With an integral journal the test results might be more consistent.

The writer would like to ask the authors why they chose to publish Fig. 16 when it was not representative of the results of several tests of Satco metal? They state in the text that "the length of time, 30 minutes, is accidental. Other linings of same material wiped shortly after the needle valve was closed." They then add, "As mentioned before, this time depended mostly on the condition of the bearing surface." Do they mean that this is true of every time chart shown? If that is so, it would appear that they should have charted the influence of finish upon the time before failure for each pair of materials used. They might also have shown the influence of the character of the lubricant upon the time. On the whole it appears that this series of experiments should be looked upon as only begun, and the present report as incomplete and inconclusive.

C. H. BIERBAUM.[11] The entire test as made may be termed a destructive test, both as regards design and operation; that is, the material was tested to destruction and not within practical working limits.

In all bearing testing, not only the bearing material, but the shaft or journal as well, should be studied microscopically and metallographically. The chemical composition of the bearing sleeve is given; however, it does not mention whether in a heat-treated condition or not, nor does it give the conditions of the surface of the sleeve after the test was completed. The report, however, does state that "a considerable amount of iron" was found in the drained-off oil. What does this mean? Was the sleeve subjected to a polishing or roughing effect? Since the best bearing conditions require that a mutual polishing effect should exist between the bearing and the journal, the resulting or final condition of the surface of the journal is just as important as that of the bearing surfaces.

The entire work done on the cold rolling and cold working of the material, as shown in this paper, does not seem to the writer to have any relation to bearing testing whatsoever, in that all bearing alloys should be left, as near as possible, in their natural crystallized form, without having any work done upon them to crush or break up the hard bearing crystals. Babbitts should never be peened or cold-worked to the extent of either crushing or breaking up the copper-tin or the tin-antimony crystals. The preferred condition for the application of babbitt is of course to sweat the same upon a backing, as was done in the experiments under consideration. Neither the temperature at which the molten babbitt was poured nor the temperature of the brass backing at the time of pouring is given in the report; therefore, the rate of solidifying or cooling of the molten babbitt and its consequent crystal structure is left entirely a matter of conjecture. This latter condition has a material effect upon the resulting bearing value. Best of all would have been to have had full photomicrographs and a complete metallographic study of the same.

The desirability of having the crystalline structure in addition to the chemical composition is shown very strikingly and conclusively in the remarkable babbitt tests made by Holm Graefe in the Metal Testing Laboratories of the Siemens-Schuckert-Werke A.-G., Berlin, entitled, "Der Einfluss der Giesztemperatur auf die Laufeigenschaften von Lagermetall," as reported in *Maschinenbau* of October 20, 1927. These tests were all made within the limit of practical working conditions and accordingly cannot be classified as destructive tests; they are therefore of direct practical application.

Graefe shows very interestingly the bearing value and performance of several babbitts. He shows that this bearing value of the different linings is distinctly improved by pouring the same at a high temperature on preheated shells; that is, having the cooling or solidifying of the babbitt proceed at a slow rate and thus resulting in a coarse grain. Graefe found that the performance in every case is superior where the crystallization is coarse and when the hard bearing crystals are largest. In a babbitt containing both copper and tin, of the class of babbitts which Messrs. Karelitz and Ellis have tested, the tin-copper epsilon crystal is harder than the tin-antimony crystal.

The photomicrograph (Fig. 34) shows this epsilon crystal in its entirety. It also shows within its border a darker formation having the chemical composition of $SnCu_3$. This inner or darker crystal has not sufficient time to form under severe chilling condi-

[10] Vice-President and General Manager, Kingsbury Machine Works, Philadelphia, Pa. Mem. A.S.M.E.

[11] Vice-President and Consulting Engineer, Lumen Bearing Company, Buffalo, N. Y. Life Mem. A.S.M.E.

tions, but it does form when slowly cooling, and the slower the babbitt cools, the larger the amount of this inner crystal. Now, the fact is that the darker inner crystal is the hardest tin-copper crystal known; it is appreciably harder than any crystal found in the phosphor bronzes. By the slower cooling the increased amount of this hard crystal in the babbitt may produce very favorable results, provided the mating journal is hard enough and also possesses a sufficient degree of microscopic homogeneity, in order that this darker inner crystal does not become distinctively abrasive to the journal. It seems that Graefe, in his conclusions, did not appreciate the value or hardness of this inner crystal, in that he attributes all the improvement to slow cooling

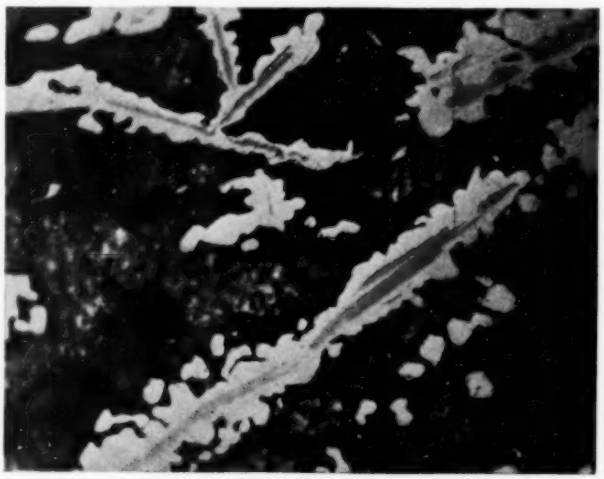


FIG. 34 PHOTOMICROGRAPH OF EPSILON CRYSTAL

and the resultant coarse grain structure. It should also be added that the physical properties of Graefe's test journal were such that it gave him the full benefit of these harder crystals.

The microhardness of the $SnCu_3$ phase, the inner dark crystal, is 1006, whereas that of the epsilon crystal, which is not of a definite chemical composition, has a microhardness near 600 or 700, even less than that of the hard delta crystal in the phosphor bronzes.[12] It is entirely possible that the variation in the amount of this hardest crystal and its behavior upon the journal accounted for some of the variable behavior of the bearings in question, as found by Messrs. Karelitz and Ellis, in that a variable amount of the residual lubricant upon the journal can readily be accounted for by a variable amount of this hard crystal.

The tooling or finishing of bearing surfaces likewise has a very important bearing upon their behavior. The final tooling should be done with very light cuts, at a high speed and with very sharp tools, in order to destroy the natural crystallization to the least possible depth. Experience on a very large scale has shown that in the finishing of sweated-in babbitt bearings, if cut with a very sharp diamond or tungsten-carbide tool at an extremely high speed, surfaces can be produced that approach very closely to a "run-in" surface, equal to those that would require weeks, if not months, by the running-in process. If the finishing is done with a few very fine cuts, and having the last cut, say, less than 0.001 in., a babbitt bearing surface can be produced with the hard bearing crystals immediately upon and flush with these finished surfaces, a condition always found in a perfect "run-in" state. A bearing surface is not completely run-in until all of the hardest crystals are flush with the bearing surface.

During the last thirty-five or forty years an enormous amount of bearing testing has been done by individuals and private corporations. If all the facts could be assembled, the aggregate amount of work done would be enormous; on the other hand, the small amount of positive information obtained is far more astounding. The answer to all of this is self-evident: tests have been made in a destructive manner; investigators hoped to obtain, by a few hours' test, actual bearing values. By strictly destructive bearing testing so far "no one has gotten anywhere and all have gotten nowhere."

A. NADAI.[13] The paper is very valuable as the authors endeavored to investigate, not only the physical conditions under which a soft bearing metal wipes, but also to determine the mechanism of wiping itself in a babbitt. In this respect the writer would like to support the general proceeding of the authors in their interesting tests and especially the fact that they tried to exaggerate certain conditions in their tests. They succeeded by this method in finding the important result that wiping in a bearing means melting of a component in the babbitt-metal lining.

The writer would be interested to know more about the mechanical conditions which are present in the small portion of the surface of a bearing in which the shaft actually wipes on the bearing shell. The normal pressure at the points of contact will be certainly comparatively large. He would like to ask if the authors have perhaps investigated also the average value of the tangential stress component in the surface of contact, because the actual conditions of wear may perhaps be determined more exactly if both components, the normal and the tangential, at the points of contact, could be predicted. It is perhaps possible that also the tangential component may have a greater effect on the wiping.

AUTHORS' CLOSURE

With reference to Mr. Howarth's remarks, the authors' intention was to emphasize the fact that independently of the conditions of finish and the time necessary to produce the first seizure of the shaft, the temperature registered by the thermocouple near the skin layer of babbitt was a temperature characteristic of the babbitt material. It is very important to note that this temperature was registered without any control of oil conditions or particular care to produce uniform finish. The same refers in part to Mr. Bierbaum's discussion. A record of all the details of composition and condition of the shaft would obscure the issue rather than be useful in this instance. The temperature of pouring was not controlled beyond the ordinary shop process control. A thorough study of the finer points of influence of the finish and oil on the time of running between lubrication stoppage and first seizure and the influence of the pouring temperature, if any, on the wiping temperature would, no doubt, be very interesting.

The results of the tests on cold rolling are reported as a continuation of the measurements of strength of the tin-copper-antimony series given in the first part of the paper. It is true that we do not possess at present any reliable simple test which would prove or disprove the suitability of a babbitt as a bearing metal. We must therefore go through all the "destructive" tests and by comparing with actual experience come to some conclusions. Now, however, we are in a position to add the wiping test to the tests dealing with mechanical strength only. It is true that the cold-rolling test is no more justified than a Brinell test, in so far as it does not at all represent the true working conditions of a bearing metal. However, in such applications as internal-combustion engines, the ductility of the babbitt is rather important, and in some instances this property may serve as a guide in the choice of the proper material.

[12] "Study of Bearing Metals," C. H. Bierbaum, A.I.M.E., Feb., 1923.

[13] Research Department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Mem. A.S.M.E.

MSP-52-8

Present Practice in the Use of Cutting Fluids[1]

Progress Report No. 2 of the Sub-Committee on Cutting Fluids[2] of the A.S.M.E. Special Research Committee on Cutting of Metals

COMPILED BY S. A. McKEE,[3] WASHINGTON, D. C.

This report is an attempt to indicate, in so far as its scope will permit, either the trend or lack of trend, as the case may be, toward the use of a particular type of cutting agent for a given maching operation on a given kind of metal. It is based on information obtained from sixty-eight of the large users of cutting fluids in this country. Nine tables are presented. The first of these is a general summary. It lists the number of plants using any of three general types of cutting agent (dry, water or emulsions, oils or oil mixtures) for each of nineteen maching operations on eight kinds of metals. Each of the remaining eight tables gives more detailed information pertaining to the cutting agents used for the various operations on a given metal.

THIS report contains the tabulated returns from the blank chart published as Appendix No. 2 of the previous report,[4] which was distributed to the largest users of cutting fluids in the United States and returned by them with the blanks filled in.

This chart with its accompanying notes is practically self-explanatory. The upper portion provides spaces for indicating the types of cutting fluids used with nineteen of the common machining operations on eight kinds of metals, extra spaces being provided for operations or materials not listed. The lower portion was provided as an aid to the user in properly classifying the cutting fluids into general groups. Nearly all of the replies received contained the information in a suitable form.

Usable data were received from 75 plants of 68 of the large users of cutting fluids in this country. These data comprise over 12,000 individual returns, representing current practice of the leading manufacturers of automotive, steam, and electrical machinery, machine tools, and other products.

In some instances the information returned was vague or incomplete. Thus on several of the charts the trade name but not the classification of the cutting fluid was given. Accordingly a questionnaire was sent to the producers of the fluids mentioned by the users, and to some others, to obtain information (considered as confidential and not for publication) regarding the ingredients of various trade-name fluids. For the most part these companies gave the desired information, thus amplifying the scope of the data obtained from the users' charts.

Correlation of Data. An attempt has been made to correlate the data by the use of composite tables which are essentially a summary of all those received from the various companies.

The first and least complex of these is Table 1. In this the eight materials are listed across the top and the nineteen operations along the left border. Each column for a given material is subdivided into three parts for indicating the general type of cutting agent used. The headings for these sub-columns, A, B, and C, denote "dry" (including air-blast), "water or emulsions," and "oils, oil mixtures, etc.," respectively. In order to simplify the table, the lines for indicating the kind of duty for each operation have been limited to two; those labeled L indicate light or finishing cuts, and H heavy or roughing cuts.

The numbers recorded in each individual space in Table 1 indicate the number of plants that used that type of cutting agent on the particular operation, kind of duty and material indicated by the headings at the top and along the left border. For example, in the turning of low-carbon steel while making heavy or roughing cuts, 17 plants reported that they did the operation dry, 27 used water or a water emulsion, and 19 used an oil or oil mixture without water.

In some instances the manufacturer indicated that a particular cutting agent was used for all kinds of duty in a given operation. Wherever this occurred it was assumed that both types were implied, and that particular cutting agent was then counted under both H and L. In the few cases where a plant reported more than one kind of fluid for a given operation, for the sake of simplicity each fluid was given full credit for the operation. This was considered justifiable since the instances were few and at best the table is a very rough approximation.

A more detailed correlation of the data is given by Tables 2 to 9, inclusive. Each of these summarizes the returns for a given kind of metal. The 19 operations with two kinds of duty and the three general types of cutting agents are listed as in Table 1. Sections B (water or emulsions) and C (oils, oil mixtures, etc.), however, are each subdivided into four columns.

In the first column, labeled "Number of Users," is given the total number of plants which reported the use of that general type of fluid for the given operation. The second, labeled "Kinds of Fluids of Known Formula," indicates the number of kinds of fluids of that type that were mentioned, for which definite information regarding their formulas was available. The number of plants that reported a fluid that was known to be of the given general classification, but upon which definite information regarding its formula was incomplete, is listed in the third column labeled "Plants Reporting Fluids of Unknown Formula." In the fourth column, "Fluids Most Used," there are listed by symbols the fluids of known formulas that were most frequently reported for a given operation. The small subscript number after each symbol represents the number of users who reported the use of that particular fluid for the given operation.

As an example of the information obtainable from Tables 2 to 9 inclusive, consider the case of rough or heavy turning of low-carbon steel as given in Table 2. Seventeen plants reported that they did this operation dry; 27 reported the use of water or water emulsions. Among the various fluids of this type reported, there

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[1] Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

[2] The personnel of this Sub-Committee consists of Kenneth H. Condit, New York, N. Y., *Chairman;* B. H. Blood, Hartford, Conn.; O. W. Boston, Ann Arbor, Mich.; A. L. De Leeuw, New York, N. Y.; M. D. Hersey, Washington, D. C.; W. Yonkman, Chicago, Ill.; and (ex-officio) W. W. Nichols, Detroit, Mich., *Chairman,* A.S.M.E. Special Research Committee on Cutting of Metals.

[3] Associate Mechanical Engineer, Friction and Lubrication Section, Bureau of Standards.

[4] "Cooling and Lubrication of Cutting Tools," Progress Report No. 1 of the Sub-Committee on Cutting Fluids, A.S.M.E. Special Research Committee on Cutting of Metals, presented at the Annual Meeting, December, 1928, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Reprinted, with discussion (in part), Trans. A.S.M.E. MSP-51-8, pp. 47–58, 1929.

Contributed by the Sub-Committee on Cutting Fluids of the A.S.M.E. Special Research Committee on Cutting of Metals and presented at the Annual Meeting, New York, N. Y., Dec. 2 to 6, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

TABLE 1 SUMMARY OF RETURNS FROM SEVENTY-FIVE PLANTS SHOWING PRESENT PRACTICE IN THE USE OF CUTTING FLUIDS

		Material																							
		Steel												Cast iron			Brass			Copper			Aluminum		
		Low-carbon			High-carbon			Cast			Alloy														
Operation	Kind of duty	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Turning	H	17	27	19	17	21	20	17	21	14	15	21	27	44	6	1	30	10	13	16	7	12	9	8	20
	L	16	27	23	16	20	22	17	19	17	12	22	33	46	5	1	31	10	12	13	9	12	6	8	23
Boring	H	15	27	16	14	21	18	18	22	14	11	17	25	43	7	1	25	12	11	12	8	11	9	7	18
	L	13	24	21	13	17	22	16	18	19	10	16	28	44	6	1	28	12	10	11	8	11	6	9	21
Drilling	H	2	50	23	2	36	25	1	41	18	1	30	31	44	10	1	29	11	10	9	10	11	8	8	27
	L	3	44	23	3	33	23	2	39	17	2	28	31	43	9	1	30	11	11	10	11	13	8	8	29
Reaming	H	3	26	40	2	20	36	2	22	33	2	14	38	35	6	11	17	16	16	3	7	20	4	9	26
	L	4	25	43	3	18	42	2	19	37	2	16	43	37	6	14	21	16	17	5	7	21	4	8	27
Threading	H	1	18	57	2	7	50	1	13	41	0	9	49	27	4	14	16	13	19	3	9	18	3	5	30
	L	1	19	60	2	8	56	1	13	44	0	8	53	29	3	16	18	13	22	3	9	19	3	5	29
Tapping	H	0	11	61	2	3	52	0	8	49	0	4	55	17	8	31	16	12	25	1	10	21	5	4	32
	L	0	11	64	2	4	55	0	9	48	0	5	55	18	8	33	18	12	27	1	10	21	4	3	32
Milling	H	1	40	24	2	30	28	2	31	17	0	29	27	41	9	2	26	13	7	5	8	13	10	9	19
	L	1	39	30	2	29	34	2	31	22	0	25	33	43	8	2	31	12	8	5	9	14	7	10	23
Shaping	H	31	1	4	29	0	4	29	1	3	28	0	4	34	0	1	26	0	1	17	1	2	15	0	9
	L	34	1	7	30	0	7	29	1	6	28	0	4	37	0	1	29	1	1	18	1	3	15	0	10
Planing	H	34	2	4	29	0	4	31	1	3	32	0	5	36	0	0	27	0	1	16	1	1	13	0	10
	L	32	3	8	30	1	8	30	2	7	31	1	10	38	0	0	30	0	1	16	1	2	12	0	13
Gear cutting	H	1	10	40	1	9	33	2	9	24	0	8	29	26	5	2	16	6	13	2	3	7	2	3	8
	L	1	9	42	1	7	36	2	8	26	0	7	32	27	6	2	18	6	12	3	3	7	2	3	8
Gear hobbing	H	1	7	34	1	5	32	1	5	25	0	5	26	22	3	1	14	3	8	1	2	7	1	2	8
	L	1	7	35	1	4	34	1	5	26	0	5	27	23	4	1	14	3	9	2	2	7	1	2	8
Automatic machines	H	0	4	51	0	4	45	0	2	25	0	4	42	6	0	3	2	2	26	0	1	17	1	1	13
	L	0	6	53	0	6	47	0	3	27	0	5	43	8	0	3	2	3	28	0	3	17	1	2	14
Turret lathes	H	1	29	35	0	21	31	1	18	23	0	16	32	29	3	4	16	12	16	3	11	16	5	5	19
	L	1	26	39	0	22	34	1	17	26	0	16	36	31	3	4	16	12	19	4	10	19	4	5	24
Slotting	H	13	10	21	13	7	19	11	7	19	12	7	21	27	0	4	22	2	6	7	3	8	6	2	13
	L	15	11	19	15	8	16	11	7	17	12	8	19	27	0	3	23	2	5	7	3	9	7	3	12
Broaching	H	2	7	35	1	6	29	2	6	22	1	4	28	13	6	7	6	8	14	0	4	8	1	2	13
	L	2	8	37	1	6	32	2	6	25	1	4	30	14	6	6	9	8	14	1	4	8	1	2	15
Cutting off	H	2	18	32	3	17	28	2	13	22	2	20	29	23	6	4	15	9	11	3	8	10	5	4	14
	L	2	21	35	3	19	31	2	13	25	2	21	32	27	6	3	15	9	13	4	8	13	4	4	17
Cold sawing	H	4	32	27	4	27	24	2	22	18	5	30	19	17	10	6	11	11	11	6	7	9	6	4	11
	L	5	34	24	4	32	24	3	24	17	6	33	19	20	10	6	16	12	10	7	8	9	7	4	11
Grinding	H	4	56	2	4	57	1	2	44	1	2	55	1	9	30	2	7	23	2	4	12	2	2	9	8
	L	4	57	3	5	57	1	2	41	2	3	57	1	9	32	1	7	27	2	4	15	2	2	10	9
Lapping	H	1	1	17	1	2	21	1	1	13	1	2	17	2	0	13	0	0	6	0	0	5	0	0	3
	L	1	1	20	1	2	24	1	1	16	1	2	21	2	0	15	0	0	7	0	0	6	0	0	4

KEY TO SYMBOLS

Symbols for Kind of Duty
- H = Heavy or roughing cut
- L = Light or finishing cut

Symbols for Class of Fluid Used
- A = Dry cutting, including air-blast
- B = Water or emulsions
- C = Oils, oil mixtures, etc.

Symbols for Individual Fluids

In Class B
- E = Water + alkali
- F = Water + alkali + fatty oil
- G = Water + alkali + fatty oil + mineral oil
- J = Water + fatty oil + mineral oil
- K = Water + fatty oil + mineral oil + soap
- M = Water + mineral oil + soap
- Z = Water + oil + sulphur

In Class C
- N = Fatty oil
- P = Fatty oil + mineral oil
- Q = Fatty oil + mineral oil + kerosene
- R = Fatty oil + mineral oil + kerosene + sulphur
- S = Fatty oil + mineral oil + sulphur
- T = Fatty oil + turpentine
- U = Mineral oil
- V = Mineral oil + kerosene
- W = Kerosene
- Y = Beeswax

were 5 different kinds of which the ingredients were known; 7 reported fluids upon which information was incomplete; and "water + mineral oil + soap" (M) was the fluid most frequently reported, this type of fluid being used by 13 plants. Nineteen reported the use of oils or oil mixtures. Among this type of fluids 6 kinds were of known formula, and 3 plants reported fluids upon which information was incomplete. Two types of oils were reported most frequently, blends of fatty and mineral oils (P), and blends of fatty and mineral oils + a small percentage of sulphur (S), the former being reported by 7 and the latter by 5 plants.

Kind of Cutting Agents Reported. The following basic materials were used to make up the numerous cutting agents reported: water, alkali (usually some form of soda), animal fats and oils, vegetable oils, mineral oils (including kerosene), carbon tetrachloride, turpentine, sulphur, soap, whitelead, beeswax, talc, lampblack, petrolatum, and compressed air in the form of air-blast.

Discussion

W. YOUKMAN.[5] In the general summary there is little agreement among the users as to the proper cutting fluids for turning, boring, and slotting operations on steels, while in the case of non-ferrous metals and cast iron there appears to be a fairly definite agreement. In practically all of the other operations on both ferrous and non-ferrous metals, there seems to be a definite trend toward some sort of an agreement as to the type of cutting fluids to be used. On the other hand, the differences in practice which do exist suggest the need of further study to furnish definite data on which to base an improved practice in the future.

O. W. BOSTON.[6] The report, based on a questionnaire submitted to a number of users of oils, shows in a very general way some interesting trends so far as the use of the three classes of cutting fluids is concerned. Specific information, however, seems to be lacking, and the value of the paper for commercial or scientific purposes is questioned.

It seems unfortunate that the much-used medium carbon steel was not included among the materials reported on. There appears to be some confusion in Table 9 as to whether "aluminum" is the pure aluminum or aluminum alloy. Pure aluminum machines differently from its alloys, so that this table gives

[5] Manufacturing Department, Western Electric Company, Chicago, Ill.

[6] Professor of Shop Practice, Director of Engineering Shops, University of Michigan, Ann Arbor, Mich. Mem. A.S.M.E.

results that are ambiguous and probably questionable. The brass reported in Table 7 probably covers a wide variety of compositions. Some distinction should have been made between those of the leaded and non-leaded types because of their difference in cutting action.

In Table 6 and elsewhere the report of the fluids most used does not include class A, which appears to be used most commonly. Also class A, referred to as dry cutting, including an air blast, probably is meant to include air suction, which is used most commonly in production work to remove the fine particles of dust of the cast iron, as well as to furnish, perhaps, a slight degree of cooling. The use of an air blast in cutting cast iron is not common, although the tabulations do not point this out.

Many users of cutting oils buy simply by trade name, and it seems only appropriate that such a classification should specifically state the exact type, specific composition, or trade name, which according to the fundamental classification is definitely located in the group. The exact composition of each trade-name composition would, of course, have to be known. A classification that is used by the writer is appended as a suggestion. This table gives a variety of sub-classes under each main heading, and under each sub-class are given several specific types. Oils are divided into six main headings under *D*, as fixed oils, mineral oils, compounded or blended oils, sulphurized mineral-oil bases, sulphurized lard-oil bases, and mineral oil with oleic acid. The fixed oils are subdivided into animal, fish, and vegetable oils, each of which is further subdivided into specific oils. Mineral oils are subdivided into kerosene and lubricating oils of various viscosities, such as 28 deg. B. pale paraffin, red engine oil, etc. It probably would be more satisfactory to represent the paraffin, red engine, and heavy engine oils by their viscosity at 100 deg. fahr., as indicated. Under the oil classification, therefore, lard oil would be represented by *D* 1 *a* (1) pale mineral oil (100 viscosity at 100 deg. fahr.) by *D* 2 *b*, etc. Under such a heading either viscosities or percentages could easily be added, so that the information given would be specific. For instance, if in grinding, tri-sodium phosphate were used, mixed in proportion of 1 lb. of grinding compound to 50 lb. of water, it could be specified as *C* 3 *e* (1 to 50). This 1 to 50 may be expressed as 2 per cent.

It is realized that this classification should be extended to cover all desirable types of oils or trade names, but in the end the classification would be specific, or if only general information was needed, only the first one or two symbols of the classification could be used.

As a member of the sub-committee sponsoring this report, the writer is offering his suggestions because he is not wholly in accord with the report. He feels that such a classification should be of value to the man in the shop, the production engineer, or the purchasing agent, and he very much questions the value of the information presented for this purpose.

Classification of Cutting Fluids

A Dry
- 1 Dry
- 2 Air blast
- 3 Air suction

B Aqueous solutions
- 1 Water
- 2 Water plus alkali
  - *a* Borax
  - *b* Soda ash or sal soda
  - *c* Trisodium phosphate
  - *d* Also various trade names representing various compositions

C Emulsions, soluble oils and compounds
- 1 A mineral oil compounded with a neutralized sulphonated fixed oil; to be mixed with water
- 2 A mineral oil compounded with an alcoholic solution of soap; to be mixed with 10 to 50 parts of water
  (Various compositions designated by trade name or symbol)
- 3 A cutting paste made of thick soap solution and mineral oil; to be mixed with 10 to 50 parts of water
  (Various compositions designated by trade name or symbol)
- 4 Non-alcoholic soap-base soluble oils
  (Various compositions designated by trade name or symbol)
- 5 Ohter special mineral-lard oils; emulsified with an alkali
  (Various compositions designated by trade name or symbol)
- 6 Synthetic mineral soluble oil
  (Various compositions designated by trade name or symbol)
- 7 Milk
  - *a* Fresh milk for cutting copper
  - *b* Sour milk for cutting aluminum

D Oils
- 1 Fixed oils
  - *a* Animal
    - (1) Lard
    - (2) Tallow
    - (3) Neat's-foot
    - (4) Wool
    - (5) Horse
    - (6) Sperm
    - (7) Whale
  - *b* Fish
    - (1) Menhaden
  - *c* Vegetable
    - (1) Olive
    - (2) Rapeseed
    - (3) Cotton seed
    - (4) Mustard seed
    - (5) Castor oil
    - (6) Peanut oil
    - (7) Soya bean oil
    - (8) Corn oil and distillate oils
    - (9) Creosote
    - (10) Turpentine
    - (11) Rosin
- 2 Minerals oils
  - *a* kerosene
  - *b* (100 viscosity at 100 deg. fahr.)
  - *c* (200 viscosity at 100 deg. fahr.)
  - *d* (300 viscosity at 100 deg. fahr.)
- 3 Compounded or blended oils
  - *a* Fixed
  - *b* Mineral
  - *c* Fixed and mineral
    (Various compositions designated by symbol or trade name)
- 4 Sulphurized mineral oils (straight or diluted with 3 to 6 parts *D* 2 *b*)
  (Various compositions designated by symbol or trade name)
- 5 Sulphurized lard-oil base (straight or diluted with 5 to 20 parts *D* 2 *b*)

(Various compositions designated by symbol or trade name)

6 Mineral oil with oleic acid

(Various compositions designated by symbol or trade name)

RALPH E. FLANDERS.[7] The writer disagrees with the suggestion that cutting fluids should be called coolants on the assumption that their only function is to carry away heat.

Most "coolants" perform two functions; that of carrying away heat and also that of lubricating or otherwise affecting the cutting action so as to give a smooth finish. In general, the use of oils tends to improve the finish, but decreases the heat-carrying power. While pure water, with the addition of some chemical to prevent it from rusting the machine, is superior in heat-carrying power, it does not give a good finish. Most practical cutting compounds are a compromise between these two qualities.

The writer was much impressed with the necessity for lubricating characteristic in cutting oils in connection with a recent experience. Some Acme thread chasers had been made which were to be used in a shop in St. Louis. In our own shop on the material used in the St. Louis shop these chasers cut a beautiful thread. In the customer's shop in St. Louis they cut very poor threads. Nothing that could be done at long range solved the mystery of good performance in our shop and of poor performance in the customer's shop. A visit with two or three days' investigation brought no light to the problem until the cutting oil came under suspicion. It was shut off from the machine, and a can of ordinary emulsion of some sort from a nearby engine lathe was turned on the bar of stock while the thread was being cut, and instantly a fine finish was obtained. In other words, the supposedly cheaper cutting compound gave very much better results than the oil.

It is surmised that the oil used was lacking in that quality of "oiliness" of which Dr. Hershey speaks, while the very small amount of oil in the cutting compound was rich in that quality. It is hoped that some time apparatus will be devised to measure this quality more or less directly as it seems to be a very important one.

While it is indubitable that oils and cutting compounds have some lubricating effect which affects the quality of the finish, this action must take place on the under side of the chip between the tool point and the work. At cutting speeds of 75 to 150 ft. per min., it is very difficult to understand how enough of the liquid gets in there to make any particular difference, but get in there it does somehow, perhaps by capillary attraction or perhaps by adsorption—whatever that may be. The whole matter is mysterious, but that does not prevent making practical use of the mysterious qualities.

[7] Manager, Jones & Lamson Machine Company, Springfield, Vt. Mem. A.S.M.E.

AUTHOR'S CLOSURE

Professor Boston's point regarding symbol (A), dry cutting including air blast, is well taken, since with few exceptions the symbol (A) refers to the usual type of dry cutting. Air blast was reported by one plant only. It was used for drilling and reaming operations on cast iron and for threading and tapping operations on cast iron and brass. Air suction was not mentioned by the plants that answered the questionnaire.

The main part of Professor Boston's discussion is built around the question of specific versus general information. It is realized that a minutely detailed classification of operations, metals, and cutting fluids would be more desirable. It should be pointed out, however, that a questionnaire of a scope suitable to obtain this complete detailed information would of necessity have to be too elaborate from the standpoint of obtaining reasonable cooperation from the plants. Thus the choice boils down to either sending out a questionnaire of a general nature from which a reasonable percentage of replies will be received or one that is so detailed as to require an expenditure of more work to fill in than can reasonably be expected.

In conclusion it should be noted that the classification to be followed in analyzing the returns was not optional with the present author, as it was fixed by the questionnaire sent out, which in turn formed a part of the previous Progress Report[8] and had already been approved by the sub-Committee.

[8] "Cooling and Lubrication of Cutting Tools," loc. cit.

TABLE 2 LOW-CARBON STEEL—DETAILED RETURNS

Operation	Kind of duty	(A) Dry: Number of users	(B) Water or Emulsions: Number of users	(B) Kinds of fluids of known formula	(B) Reporting fluids of unknown formula	(B) Fluids most used	(C) Oils or Oil Mixtures: Number of users	(C) Kinds of fluids of known formula	(C) Reporting fluids of unknown formula	(C) Fluids most used
Turning	H	17	27	5	7	M_{13}	19	6	3	P_7, S_5
	L	16	27	5	10	M_{10}	23	8	2	P_9, S_4
Boring	H	15	27	6	7	M_{12}	16	4	2	P_8, S_6
	L	13	24	5	7	M_7	21	7	2	P_6, S_5
Drilling	H	2	50	8	13	M_{23}	23	5	3	P_5, S_4
	L	3	44	7	12	M_{21}	23	5	4	P_{10}
Reaming	H	3	26	6	4	M_{15}	40	7	3	P_{13}, U_9, N_3
	L	4	25	5	5	M_{14}	43	8	3	P_{14}, U_8, N_3
Threading	H	1	18	4	8	M_7	57	8	4	P_{15}, N_{11}
	L	1	19	4	8	M_8	60	8	5	P_{18}, N_{12}
Tapping	H	0	11	2	4	M_8	61	11	4	P_{20}, N_{10}
	L	0	11	2	4	M_6	64	11	5	P_{20}, N_{12}
Milling	H	1	40	7	11	M_{14}	24	6	5	P_8
	L	1	39	6	12	M_{12}	30	7	5	P_{11}
Shaping	H	31	1	1	0	J_1	4	1	2	P_2
	L	34	1	1	0	J_1	7	2	2	P_4
Planing	H	34	2	2	0	E_1, M_1	4	2	2	P_2
	L	32	3	2	0	M_2, E_1	8	2	2	P_5
Gear cutting	H	1	10	2	3	M_6	40	5	7	P_{12}, S_8
	L	1	9	3	2	M_5	42	5	5	P_{15}, S_7, N_7
Gear hobbing	H	1	7	2	3	M_2	34	5	7	P_{10}, S_8, U_8
	L	1	7	3	3	M_2	35	5	6	P_{12}, S_6, U_8
Automatic machines	H	0	4	2	2	F_1, J_1	51	7	5	P_{16}, U_{10}, N_8
	L	0	6	3	2	M_2	53	7	5	P_{17}, U_{10}, S_8
Turret lathes	H	1	29	4	7	M_{15}	35	6	3	P_{20}
	L	1	26	4	7	M_{13}	39	6	4	P_{22}
Slotting	H	13	10	2	5	M_4	21	6	0	P_9
	L	15	11	2	5	M_5	19	6	0	P_9
Broaching	H	2	7	2	1	M_3	35	7	1	P_{12}, N_{11}
	L	2	8	3	1	M_3	37	7	2	P_{11}, N_{11}
Cutting off	H	2	18	5	3	M_{10}	32	5	4	P_{15}
	L	2	21	5	4	M_{12}	35	6	4	P_{17}
Cold sawing	H	4	32	7	5	M_{17}	27	8	5	P_{10}
	L	5	34	7	6	M_{19}	24	8	3	P_9
Grinding	H	4	56	6	16	E_{17}, M_{14}	2	1	1	P_1
	L	4	57	6	18	E_{17}, M_{14}	3	1	2	P_1
Lapping	H	1	1	1	0	J_1	17	7	0	P_6, U_3, W_2
	L	1	1	0	1	..	20	7	0	P_7, W_4, U_3

TABLE 3 HIGH CARBON STEEL—DETAILED RETURNS

Operation	Kind of duty	(A) Dry: Number of users	(B) Water or Emulsions: Number of users	(B) Kinds of fluids of known formula	(B) Reporting fluids of unknown formula	(B) Fluids most used	(C) Oils or Oil Mixtures: Number of users	(C) Kinds of fluids of known formula	(C) Reporting fluids of unknown formula	(C) Fluids most used
Turning	H	17	21	4	6	M_9	20	5	3	S_7, P_5
	L	16	20	5	8	M_8, J_2	22	7	2	P_6, S_5
Boring	H	14	21	6	5	M_8	18	4	2	S_7, P_5
	L	13	17	5	5	M_8, J_2	22	7	2	S_6, P_5, N_4
Drilling	H	2	36	7	11	M_{16}	25	5	4	P_6, S_6, N_3
	L	3	33	6	11	M_{15}	23	5	5	P_6, N_4
Reaming	H	2	20	6	3	M_{11}	36	7	4	N_8, P_8, S_6
	L	3	18	5	4	M_9	42	8	4	N_{10}, P_{10}, S_8
Threading	H	2	7	2	4	M_2	50	8	5	N_{13}, P_{12}
	L	2	8	2	4	M_2	56	8	6	N_{16}, P_{14}
Tapping	H	2	3	1	1	M_2	52	10	4	P_{18}, N_{10}, U_9
	L	2	4	1	2	M_2	55	10	4	P_{16}, N_{12}, U_8
Milling	H	2	30	6	9	M_{14}	28	6	6	N_7, P_6
	L	2	29	5	10	M_{13}	34	7	6	P_{10}, N_7
Shaping	H	29	0	0	0	..	4	3	1	N_1, P_1, S_1
	L	30	0	0	0	..	7	3	1	P_3, N_2, S_1
Planing	H	29	0	0	0	..	4	2	1	P_2
	L	30	1	1	0	M_1	8	2	1	P_4
Gear cutting	H	1	9	2	3	M_5	33	4	7	P_8, S_7, U_6
	L	1	7	2	2	M_4	36	5	5	P_{10}, S_7, N_7
Gear hobbing	H	1	5	2	2	M_2	32	5	6	P_7, S_7, U_6
	L	1	4	2	2	F_1, M_1	34	6	5	P_9, S_7, U_6
Automatic machines	H	0	4	2	2	F_1, J_1	45	6	5	P_{13},U_{10},S_7,N_7
	L	0	6	3	2	M_2, F_1, J_1	47	6	5	P_{14},U_{10},S_6,N_6
Turret lathes	H	0	21	4	6	M_{15}	31	6	4	P_{20}
	L	0	22	4	7	M_{13}	34	6	4	P_{22}
Slotting	H	13	7	2	3	M_3	19	5	2	P_6, N_4, S_4
	L	15	8	2	3	M_4	16	5	2	P_5, N_3, S_3
Broaching	H	1	6	1	1	M_3	29	6	1	N_{10}, P_7, S_6
	L	1	6	1	1	M_3	32	7	2	N_{11}, P_6, S_6
Cutting off	H	3	17	5	4	M_9	28	5	3	P_{12}
	L	3	19	5	5	M_9	31	6	3	P_{13}
Cold sawing	H	4	27	7	4	M_{18}	24	7	3	P_9
	L	4	32	7	6	M_{17}	24	7	2	P_8
Grinding	H	4	57	6	18	M_{16}, E_{18}	1	0	1	...
	L	5	57	6	19	E_{16}, M_{18}	1	0	1	...
Lapping	H	1	2	2	0	J_1, M_1	21	6	0	P_6, U_3
	L	1	2	1	1	M_1	24	6	0	P_7, N_3, U_3

TABLE 4 CAST STEEL—DETAILED RETURNS

Operation	Kind of duty	(A) Dry: Number of users	(B) Water or Emulsions: Number of users	(B) Kinds of fluids of known formula	(B) Reporting fluids of unknown formula	(B) Fluids most used	(C) Oils or Oil Mixtures: Number of users	(C) Kinds of fluids of known formula	(C) Reporting fluids of unknown formula	(C) Fluids most used
Turning	H	17	21	4	5	M_{11}	14	4	4	P_6, S_4
	L	17	19	4	6	M_8	17	5	3	P_6, S_4
Boring	H	18	22	4	5	M_{11}	14	3	3	S_5, P_4
	L	16	18	4	5	M_7	19	6	3	S_5, P_5
Drilling	H	1	41	9	11	M_{19}	18	5	4	P_4, S_4, U_3
	L	2	39	7	11	M_{19}	17	5	4	P_5, S_5, U_3
Reaming	H	2	22	6	4	M_{12}	33	7	4	P_{10}, N_7
	L	2	19	5	4	M_{10}	37	7	4	P_{10}, N_8
Threading	H	1	13	3	6	M_5	41	7	4	P_{11}, N_9
	L	1	13	3	6	M_5	44	9	5	P_{12}, N_9
Tapping	H	0	8	2	3	M_3	49	10	5	P_{15}, N_9
	L	0	9	2	4	M_4	48	11	6	P_{14}, N_9
Milling	H	2	31	5	8	M_{17}	17	5	6	P_8
	L	2	31	5	9	M_{16}	22	7	6	P_7
Shaping	H	29	1	1	0	J_1	3	1	2	P_1
	L	29	1	1	0	J_1	6	2	2	P_2, N_1
Planing	H	31	1	1	0	J_1	3	1	2	P_1
	L	30	2	2	0	J_1, M_1	7	2	2	P_4, N_1
Gear cutting	H	2	9	3	2	M_5	24	4	6	P_6, N_4,S_5,U_4
	L	2	8	3	1	M_5	26	5	4	P_7, N_5,U_5,S_4
Gear hobbing	H	1	5	3	1	M_2, F_1, J_1	25	5	6	N_6, U_5, S_4
	L	1	5	3	1	M_2, F_1, J_1	26	6	5	N_7, U_5, S_4
Automatic	H	0	2	1	1	F_1	25	5	3	P_{10}
	L	0	3	2	1	F_1, M_1	27	6	3	P_{10}
Turret lathes	H	1	18	4	6	M_9	23	5	2	P_{12}
	L	1	17	4	6	M_8	26	6	2	P_{14}
Slotting	H	11	7	2	3	M_3	19	5	1	P_8
	L	11	7	2	3	M_3	17	5	1	P_7
Broaching	H	2	6	1	1	M_3	22	6	0	N_9, P_5
	L	2	6	1	1	M_3	25	7	1	N_9, P_8
Cutting off	H	2	13	3	2	M_6	22	5	3	P_{10}
	L	2	13	3	2	M_8	25	6	3	P_{10}
Cold sawing	H	2	22	6	4	M_{11}	18	6	3	P_7, U_3
	L	3	24	6	4	M_{13}	17	7	2	P_6, U_3
Grinding	H	2	44	5	15	E_{13}, M_9	1	0	1	.. ..
	L	2	41	5	16	E_{12}, M_7	2	0	2	.. ..
Lapping	H	1	1	1	0	J_1	13	6	0	P_6, U_3, W_2
	L	1	1	0	1	...	16	6	0	P_8, W_4, U_3

TABLE 5 ALLOY STEEL—DETAILED RETURNS

Operation	Kind of duty	(A) Dry: Number of users	(B) Water or Emulsions: Number of users	(B) Kinds of fluids of known formula	(B) Reporting fluids of unknown formula	(B) Fluids most used	(C) Oils or Oil Mixtures: Number of users	(C) Kinds of fluids of known formula	(C) Reporting fluids of unknown formula	(C) Fluids most used
Turning	H	15	21	5	5	M_{11}	27	7	3	S_8, P_6, N_4
	L	12	22	6	8	M_8	33	9	3	P_9, S_7, N_5
Boring	H	11	17	4	4	M_9	25	6	3	P_7, S_6, U_4
	L	10	16	4	5	M_7	28	8	3	P_8, S_6, N_4, U_4
Drilling	H	1	30	5	10	M_{16}	31	8	6	S_7, P_6, N_4, U_4
	L	2	28	4	10	M_{15}	31	8	6	P_8, S_6, N_4, U_4
Reaming	H	2	14	4	1	M_{10}	38	9	5	P_9, S_6, N_5, U_3
	L	2	16	4	3	M_{10}	43	9	5	P_{10}, N_7, S_6, U_4
Threading	H	0	9	2	5	M_3	49	9	7	N_{10}, P_{10}, S_9
	L	0	8	1	5	M_3	53	9	7	P_{12}, N_{11}, S_8
Tapping	H	0	4	1	1	M_3	55	11	6	P_{15}, N_9, S_8, U_7
	L	0	5	1	2	M_3	55	11	6	P_{16}, N_9, S_7, U_6
Milling	H	0	29	5	9	M_{15}	27	8	7	P_7, N_4, S_4
	L	0	25	5	8	M_{12}	33	9	6	P_{10}, N_5, S_4
Shaping	H	28	0	0	0	..	4	3	1	P_1, S_1, T_1
	L	28	0	0	0	..	4	4	1	P_3
Planing	H	32	0	0	0	..	5	4	1	P_1, R_1, S_1, T_1
	L	31	1	1	0	M_1	10	6	1	P_4
Gear cutting	H	0	8	2	3	M_4	29	6	6	P_7, N_5, S_6, U_4
	L	0	7	2	2	M_4	32	6	5	P_8, N_4, S_6, U_4
Gear hobbing	H	0	5	3	2	M_2, F_1	26	6	6	P_6, S_5, U_4, N_3
	L	0	5	3	2	M_2, F_1	27	7	5	P_7, S_5, U_4, N_3
Automatic machines	H	0	4	2	1	M_2, F_1	42	7	6	P_9, N_8, S_7, U_7
	L	0	5	2	1	M_2, F_1	43	7	6	P_{10}, N_7, S_7, U_7
Turret lathes	H	0	16	4	4	M_9	32	8	4	P_{12}
	L	0	16	4	4	M_9	36	8	4	P_{13}
Slotting	H	12	7	2	3	M_4	21	8	3	P_9
	L	12	8	2	3	M_5	19	8	3	P_9
Broaching	H	1	4	1	1	M_2	28	8	3	N_7, P_7, S_5
	L	1	4	1	1	M_2	30	9	3	N_7, P_7, S_6
Cutting off	H	2	20	5	5	M_{10}	29	6	3	P_{11}, S_6
	L	2	21	5	6	M_{10}	32	7	3	P_{14}, S_6
Cold sawing	H	5	30	7	6	M_{14}	19	6	4	P_5, S_4
	L	6	33	7	7	M_{16}	19	6	3	P_5, S_5
Grinding	H	2	55	7	17	M_{15}, E_{12}	1	0	1	....
	L	3	57	7	18	E_{15}, M_{14}	1	0	1	....
Lapping	H	1	2	2	0	J_1, M_1	17	6	0	P_6, U_3, W_2
	L	1	2	1	1	M_1	21	6	0	P_8, W_6, V_4

TABLE 6 CAST IRON—DETAILED RETURNS

Operation	Kind of duty	(A) Dry: Number of users	(B) Water or Emulsions: Number of users	(B) Kinds of fluids of known formula	(B) Reporting fluids of unknown formula	(B) Fluids most used	(C) Oils or Oil Mixtures: Number of users	(C) Kinds of fluids of known formula	(C) Reporting fluids of unknown formula	(C) Fluids most used
Turning	H	44	6	2	1	M_4, G_1	1	1	0	P_3
	L	46	5	2	1	M_3, G_1	1	1	0	P_1
Boring	H	43	7	2	3	M_3, G_1	1	1	0	P_3
	L	44	6	2	2	M_3, G_1	1	1	0	P_3
Drilling	H	44	10	2	3	M_5	1	1	0	P_1
	L	43	9	3	3	M_4	1	1	0	P_1
Reaming	H	35	6	3	2	M_2, G_1, J_1	11	6	1	P_4, U_2
	L	37	6	3	2	M_2, G_1, J_1	14	7	2	P_4, U_2
Threading	H	27	4	2	1	M_2, Z_1	14	6	2	P_3
	L	29	3	2	0	M_2, Z_1	16	6	2	P_3
Tapping	H	17	8	3	3	Z_2, M_2	31	8	3	P_{11}, U_6
	L	18	8	3	3	Z_2, M_2	33	8	4	P_{11}, U_7
Milling	H	41	9	4	1	M_3	2	1	0	P_2
	L	43	8	4	1	M_4	2	1	0	P_2
Shaping	H	34	0	0	0	...	1	1	0	P_1
	L	37	0	0	0	...	1	1	0	P_1
Planing	H	36	0	0	0	...	0	0	0	...
	L	38	0	0	0	...	0	0	0	...
Gear cutting	H	26	5	3	1	M_2	2	1	1	S_1
	L	27	6	4	1	M_2	2	1	1	S_1
Gear hobbing	H	22	3	2	1	G_1, M_1	1	0	1	...
	L	23	4	3	1	G_1, Z_1, M_2	1	0	1	...
Automatic machines	H	6	0	0	0	...	3	1	1	P_1
	L	8	0	0	0	...	3	1	1	P_1
Turret lathes	H	29	3	1	1	M_2	4	2	1	P_2
	L	31	3	1	1	M_2	4	2	1	P_2
Slotting	H	27	0	0	0	...	4	3	0	P_2
	L	27	0	0	0	...	3	2	0	P_2
Broaching	H	13	6	2	2	M_3	7	5	0	N_3, P_2
	L	14	6	2	2	M_3	6	4	0	N_3, P_2
Cutting off	H	23	6	2	0	M_4	4	1	0	P_4
	L	27	6	2	0	M_5	3	1	0	P_3
Cold sawing	H	17	10	3	1	M_7	6	3	2	P_2
	L	20	10	4	0	M_7	6	3	2	P_2
Grinding	H	9	30	6	9	E_7, M_7	2	1	1	W_1
	L	9	32	6	9	E_8, M_8	1	0	1	...
Lapping	H	2	0	0	0	.....	13	7	0	P_2
	L	2	0	0	0	.....	15	7	0	P_4

TABLE 7 BRASS—DETAILED RETURNS

Operation	Kind of duty	(A) Dry: Number of users	(B) Water or Emulsions: Number of users	(B) Kinds of fluids of known formula	(B) Reporting fluids of unknown formula	(B) Fluids most used	(C) Oils or Oil Mixtures: Number of users	(C) Kinds of fluids of known formula	(C) Reporting fluids of unknown formula	(C) Fluids most used
Turning	H	30	10	2	3	M_8	13	4	1	P_7, S_3
	L	31	10	2	3	M_8	12	4	1	P_6, S_2
Boring	H	25	12	3	4	M_8	11	3	1	P_6, S_2
	L	28	12	3	4	M_8	10	3	1	P_5, S_2
Drilling	H	29	11	3	4	M_8	10	4	2	P_5
	L	30	11	3	4	M_8	11	4	2	P_5
Reaming	H	17	16	4	5	M_8	16	7	2	P_5
	L	21	16	4	5	M_8	17	7	2	P_6
Threading	H	16	13	2	3	M_9	19	7	2	P_5
	L	18	13	2	3	M_9	22	7	3	P_{10}
Tapping	H	16	12	2	3	M_8	25	7	3	P_8, S_4
	L	18	12	2	3	M_8	27	7	3	P_{10}, S_4
Milling	H	26	13	3	2	M_9	7	4	1	P_3
	L	31	12	3	2	M_8	8	4	1	P_4
Shaping	H	26	0	0	0	...	1	1	0	P_1
	L	29	1	1	0	M_1	1	1	0	P_1
Planing	H	27	0	0	0	...	1	1	0	P_1
	L	30	0	0	0	...	1	1	0	P_1
Gear cutting	H	16	6	2	2	M_3	13	5	1	P_6, S_3
	L	18	6	2	2	M_3	12	5	1	P_5
Gear hobbing	H	14	3	2	0	M_1	8	5	0	U_3, P_2
	L	14	3	2	0	M_1	9	4	0	P_4, U_3
Automatic machines	H	2	2	2	0	J_1, M_1	26	6	2	P_{11}
	L	2	3	2	0	M_2, J_1	28	6	2	P_{12}
Turret lathes	H	16	12	3	4	M_5	16	4	3	P_{10}
	L	16	12	3	4	M_5	19	6	3	P_{11}
Slotting	H	22	2	1	1	M_1	6	5	0	P_2
	L	23	2	1	1	M_1	5	4	0	P_2
Broaching	H	6	8	2	1	M_6	14	4	0	N_3, P_4, S_2
	L	9	8	2	1	M_6	14	4	0	N_3, P_4, S_2
Cutting off	H	15	9	3	0	M_7	11	3	2	P_4
	L	15	9	3	0	M_7	13	3	2	P_4
Cold sawing	H	11	11	3	1	M_8	11	5	3	P_4
	L	16	12	3	1	M_9	10	6	2	P_3
Grinding	H	7	23	5	8	M_6, E_4	2	1	1	V_1
	L	7	27	5	8	M_8, E_2	2	1	1	V_1
Lapping	H	0	0	0	0	...	6	4	0	P_2, U_3
	L	0	0	0	0	...	7	5	0	P_2, W_3

TABLE 8 COPPER—DETAILED RETURNS

Operation	Kind of duty	(A) Dry: Number of users	(B) Water or Emulsions: Number of users	(B) Kinds of fluids of known formula	(B) Reporting fluids of unknown formula	(B) Fluids most used	(C) Oils or Oil Mixtures: Number of users	(C) Kinds of fluids of known formula	(C) Reporting fluids of unknown formula	(C) Fluids most used
Turning	H	16	7	2	4	M_2, J_1	12	7	1	P_4, S_2
	L	13	9	2	4	M_4	12	7	1	P_3, S_2, W_2
Boring	H	12	8	2	4	M_3	11	5	1	P_4, S_2, U_2
	L	11	8	2	4	M_3	11	5	1	P_3, S_2, U_2, W_2
Drilling	H	9	10	2	4	M_3	11	6	1	P_3, U_2, W_2
	L	10	11	3	4	M_3	13	7	1	P_4, U_2, W_2
Reaming	H	3	7	1	3	M_4	20	9	2	N_4, P_4, W_3
	L	5	7	1	3	M_4	21	9	2	P_5, N_4, W_3
Threading	H	3	9	2	4	M_4	18	9	3	P_3
	L	3	9	2	4	M_4	19	9	3	P_3
Tapping	H	1	10	2	4	M_3	21	9	3	P_4, N_3
	L	1	10	2	4	M_3	21	9	3	P_4, N_3
Milling	H	5	8	3	2	M_4	13	7	2	N_2, P_3, U_2, Y_2
	L	5	9	3	2	M_4	14	7	2	N_2, P_3, U_2, W_2, Y_2
Shaping	H	17	1	1	0	M_3	2	1	1	N_1
	L	18	1	1	0	M_3	3	2	1	N_1, W_1
Planing	H	16	1	1	0	M_3	1	0	1	...
	L	16	1	1	0	M_3	2	1	1	W_1
Gear cutting	H	2	3	1	2	M_3	7	5	0	N_3
	L	3	3	1	2	M_3	7	5	0	N_3
Gear hobbing	H	1	2	1	1	M_3	7	5	0	N_3
	L	2	2	1	1	M_3	7	5	0	N_3
Automatic machines	H	0	1	1	0	J_1	17	5	4	P_3, N_3
	L	0	3	2	0	M_2, J_1	17	6	4	P_3, N_3
Turret lathes	H	3	11	4	4	M_4, J_2	16	5	3	P_7
	L	4	10	3	4	M_3, J_2	19	6	3	P_3
Slotting	H	7	3	2	0	M_3	8	6	1	U_3
	L	7	3	2	0	M_3	9	6	1	U_3, Y_3
Broaching	H	0	4	1	0	M_4	8	4	1	N_4
	L	1	4	1	0	M_4	8	4	1	N_4
Cutting off	H	3	8	4	1	M_4	10	7	1	P_3
	L	4	8	4	1	M_4	13	7	1	P_4
Cold sawing	H	6	7	2	1	M_5	9	4	2	P_3, U_2
	L	7	8	2	1	M_5	9	6	1	P_4, U_2
Grinding	H	4	12	4	4	M_4, E_2	2	1	1	V_1
	L	4	15	5	4	M_5, E_2	2	1	1	V_1
Lapping	H	0	0	0	0	...	5	3	0	P_2, V_2
	L	0	0	0	0	...	6	4	0	P_2, V_2

TABLE 9 ALUMINUM—DETAILED RETURNS

Operation	Kind of duty	(A) Dry: Number of users	(B) Water or Emulsions: Number of users	(B) Kinds of fluids of known formula	(B) Reporting fluids of unknown formula	(B) Fluids most used	(C) Oils or Oil Mixtures: Number of users	(C) Kinds of fluids of known formula	(C) Reporting fluids of unknown formula	(C) Fluids most used
Turning	H	9	8	4	3	M_2	20	9	1	W_3, U_4
	L	6	8	4	3	M_2	23	9	1	W_3, U_4
Boring	H	9	7	3	3	M_2	18	9	1	W_7, U_3
	L	6	9	4	3	M_3	21	9	1	W_3, U_3
Drilling	H	8	8	3	4	M_2	27	9	1	W_{13}, U_4
	L	8	8	3	4	M_2	29	9	1	W_{13}, U_4
Reaming	H	4	9	3	4	M_3	26	10	1	W_{11}, U_5
	L	4	8	3	4	M_2	27	10	1	W_{11}, U_5
Threading	H	3	5	1	3	M_2	30	12	1	W_{10}, U_4
	L	3	5	1	3	M_2	29	11	1	W_9
Tapping	H	5	4	1	2	M_2	32	11	3	W_{11}, U_5
	L	4	3	1	2	M_1	32	11	3	W_{10}, U_4
Milling	H	10	9	5	2	M_3	19	8	1	W_7, U_3
	L	7	10	5	2	M_4	23	8	1	W_8, U_3
Shaping	H	15	0	0	0	...	9	3	0	W_6
	L	15	0	0	0	...	10	3	0	W_7
Planing	H	13	0	0	0	...	10	3	0	W_7
	L	12	0	0	0	...	13	3	0	W_8
Gear cutting	H	2	3	1	2	M_1	8	3	0	W_6
	L	2	3	1	2	M_1	8	3	0	W_6
Gear hobbing	H	1	2	1	1	M_1	8	3	0	W_6
	L	1	2	1	1	M_1	8	3	0	W_6
Automatic machines	H	1	1	1	0	M_1	13	8	1	W_3, Q_3, S_3
	L	1	2	1	0	M_2	14	8	1	W_3, Q_3
Turret lathes	H	5	5	3	2	G_1, M_1, K_1	19	9	1	W_7
	L	4	5	3	2	G_1, M_1, K_1	24	10	1	W_7
Slotting	H	6	2	2	0	G_1, M_1	13	4	0	W_6
	L	7	3	3	0	G_1, Z_1, M_1	12	4	0	W_7
Broaching	H	1	2	1	0	M_2	13	6	0	W_8
	L	1	2	1	0	M_3	15	6	1	W_8
Cutting off	H	5	4	2	0	M_3	14	6	1	W_7
	L	4	4	2	0	M_3	17	6	1	W_7
Cold sawing	H	6	4	2	0	M_3	11	5	2	W_4, U_2
	L	7	4	2	0	M_3	11	6	1	W_4, U_2
Grinding	H	2	9	3	4	E_2, M_2	8	4	1	V_3, W_2
	L	2	10	3	4	M_3, E_2	9	5	1	V_3, W_2
Lapping	H	0	0	0	0	...	3	2	0	W_3, V_1
	L	0	0	0	0	...	4	2	0	W_3, V_1

MSP-52-9

Economies Which May Be Effected in Power Transmission

By W. W. NICHOLS,[1] DETROIT, MICH.

From an economical standpoint of maintenance, power-transmission equipment is not given careful consideration by management. It should not be left to the supervision of some old-time millwright. Belting is not given a close enough inspection upon its receipt to determine if it meets all the requirements laid down by the specifications for its purchase. Many machines upon production work are over-belted, and little attention is given to the correct determination of the size of belt necessary for the work. Heavier belts could be installed profitably. By this means unnecessary wear and tear upon countershaft clutches would be eliminated. More attention should be given to the application of the correct size of motor to individually motor-driven machine tools. Great loss and low power factor result from the methods now pursued. The question of group driving and the economies effected thereby are deserving of being more closely considered and of having their cost compared with individually motor-driven tools, both from an initial standpoint and a maintenance standpoint.

THE installation and maintenance of power-transmission equipment are not given the careful consideration by management from an economical standpoint that is given to some of the other departments of a manufacturing plant. In order that this department may be placed upon an economical and progressive basis, management must take more interest in this subject and not leave it under the supervision of some old-time millwright who uses only rule-of-thumb methods.

Construction of Leather Belting

All leather belting should fall within $^1/_{64}$ in. plus or minus in thickness, joints and laps be constructed with non-crystallizing cement, all joints to be made against a straight edge at least 4 ft. in length, no strips to exceed 50 in. in length, faces of belt to be leveled to provide at least 90 per cent of contact upon pulley face.

All belting should be inspected upon receipt to see that the foregoing requirements are fulfilled. Many plants make the statement, "We buy our belting to specification," but when asked what method of inspection is used upon receipt, reluctantly admit either that there is no standard of inspection or that they do not know. The result is that a poor quality of material is being received, with its consequent high maintenance cost.

Determination of Correct Sizes of Belting

When machines are used upon jobbing work, they must be belted to accommodate the heaviest class of work to be handled upon the machines. However, when machines are set up to run for long periods upon the same piece, considerable economy can be effected by determining the actual amount of power required and by belting accordingly. This may be done by equipment similar to that shown in Fig. 1, consisting of an electric motor mounted upon a high-lift truck and used in conjunction with a recording watt-hour meter. In smaller plants it would not be necessary to incur the expense of a high-lift truck. The motor might be mounted upon a lift-truck platform, and sufficient weight added by means of scrap material or disused castings could be piled at the opposite end of the platform from the motor to assist in holding it steadily to the floor, various motor pulleys being used to give the correct countershaft or machine speeds.

The chart from the recording watt-hour meter will show the friction load of the machine, the maximum and minimum power required by the various tools, and the time taken for the complete cycle of operations.

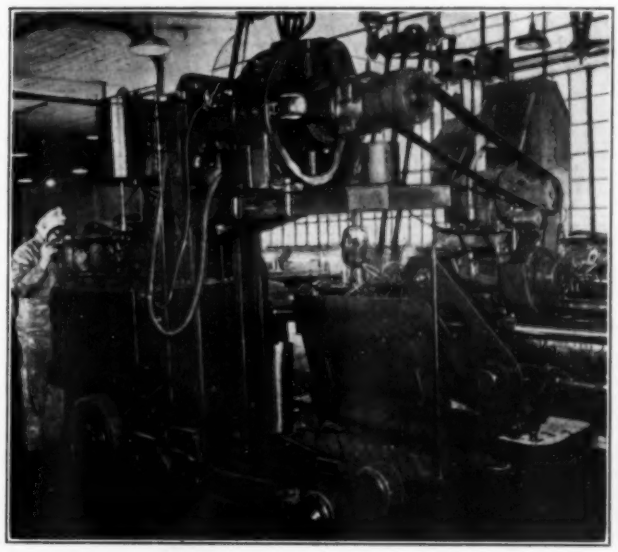


Fig. 1 Testing Equipment

The radial lines upon the recording wattmeter diagrams shown in Figs. 2 to 5 indicate half-minute intervals so that the time for a complete cycle of operations may be readily ascertained. The longitudinal lines represent the power input to the motor in watts. By this method, the total time and total power input to the motor can be measured readily and the necessary width of belt required upon the machine can be determined. By means of a wattmeter diagram, the power required for driving tools can be determined as changes in the cutting angles are effected. As an illustration of this, in one plant tests were made upon twist drills as originally ground, and it was found that 28 holes per grind was the maximum which could be produced. After experimenting with thinning the points of these drills, 220 holes were produced and an average of 178 is now being maintained. These drills were in operation upon alloy steel. The field for the application of these methods is so large and varies so greatly in the individual plants, that it is hardly possible to do more than merely to outline their application in a paper such as this, but it is the author's belief that if serious consideration is given to this subject by plant engineers or superintendents, that they can readily adapt these methods to their own conditions.

[1] Vice-President and Mechanical Engineer, D. P. Brown & Co. Mem. A.S.M.E.

Contributed by the Machine Shop Practice Division and presented at the Rochester Meeting, Rochester, N. Y., May 13 to 16, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Fig. 2 was taken from a gear-hobbing machine driven by a 5-in. belt. Upon calculation of this chart it was found that a 2-in. belt would perform the work, and such a one was installed, much against the will of the operators, but it is doing the work required. Another instance is that of a battery of over 300 Gleason gear shapers where a 2-in.-fabric belt has been installed in place of a

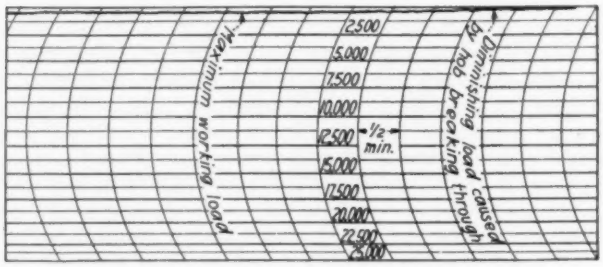


Fig. 2 Wattmeter Diagram From Gear Hobber

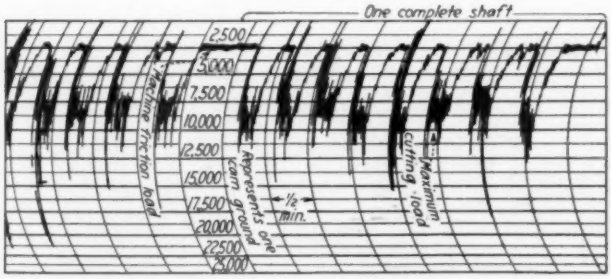


Fig. 3 Wattmeter Diagram From Norton Grinder

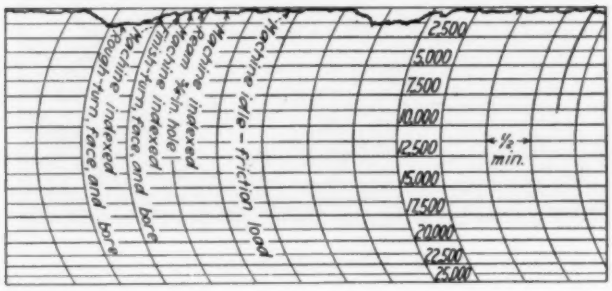


Fig. 4 Wattmeter Diagram From Potter & Johnston

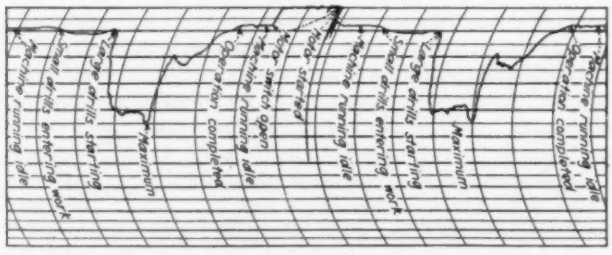


Fig. 5 Wattmeter Diagram From Rockford Drill

3½-in. double leather which effects a saving of about $35 a machine, or a total of around $10,500.

Fig. 3 was taken from a Norton grinder upon camshaft work. Note the high peak caused by the operator taking too heavy a cut.

Fig. 4 was taken from a Potter & Johnston turret lathe and shows the amount of power required for each operation.

The economies effected by these charts would not have been made if the old rule-of-thumb methods had been in use.

Heavier Weight of Belting

All have seen belts put upon pulleys at such a high tension that a rope was necessary to get them on. This means additional friction load to be overcome, wear and tear upon clutch or loose pulley and bearing wear, and additional cost of maintenance. These conditions can be remedied by the use of a heavier weight of belting, provided the pulleys are of sufficient diameter, or by wider belts of a lighter weight. Taylor's and Barth's recommendation of 190 lb. per sq. in. of belt section as the correct tension for belt application has been found by the author to be the most economical. To temporarily get out of the difficulty of a belt not pulling the required load, a rider belt has been added to the original one.

Motorization of Machine Tools

There is room for considerable improvement in the methods now employed in determining the correct size of motor upon individual machines. This will be of valuable assistance to both the machine-tool manufacturer and the user. There are two sides to this question—the manufacturer's and the user's. Often the manufacturer does not receive a definite description of the work to be performed upon the machines from the user, and the manufacturer recommends the size of motor sufficient for the maximum cut the machine is capable of pulling, which results in all probability in a very low power factor.

If the user would inform the manufacturer regarding the class of material to be operated upon and at what feeds and speeds, the latter would be able to determine the most satisfactory size of motor. But a still better method would be for the user to send sufficient of his material to the machine-tool maker for him to experiment upon and determine what would be the maximum production of the machine. There is room for a more thorough investigation by users of machine tools to determine the maximum production which machines can develop. Instances of this were brought out in one plant, where the testing outfit shown in Fig. 1 was used, indicating that production in some instances could be doubled without injury or increased grinding of tools. Other instances have occurred where requisitions for additional tools were proved to be unnecessary after tests were made. Some interesting facts developed regarding the determination of motor sizes for machine tools while the author of this paper was assisting A. F. Denham of *Automotive Industries* in the compilation of data.

The electric motor survey conducted by the National Machine Tool Builders' Association, covering all industries, showed motor sizes were specified as follows:

	By the tool manufacturer	By the user	By the dealer	Not specified
Fractional hp., %...	89	8	2	1
1–10 hp., %.....	37	47	15	1
10–15 hp., %.....	30	57	13	.

Mr. Denham[2] says, "This would seem to indicate that, taking all industries together, as the size of motors increases, more and more of the specifications come from the purchaser. Peculiarly enough this does not seem to apply to the automotive industry, to judge by replies from a number of leading machine-tool manufacturers. Thirteen out of fourteen of the largest manufacturers from whom replies were received state that they customarily specify all motors for machine tools for the automotive industry, the tools representing all types and including much special machinery.

"The manufacturers from whom replies were received can be

[2] From *Automotive Industries*, Aug. 11 and 18, 1928.

separated into four groups. In the first and largest group are those who clearly state that it is their custom to specify a motor size which will take care of the maximum load capacity of the tool without reference to the type of work for which the tool is to be used.

"In the second group can be placed those manufacturers of machine tools who offer more than one motor size for a specific tool. It will be noted, however, that even these make no effort to determine actual power requirements.

"In the third group are classed those manufacturers who determine motor sizes by computations of power required for the specific operations for which the machine is intended, basing this, by means of an empirical formula, on the amount of metal removed.

"Two manufacturers only among those replying are in the fourth group, those who actually determine the horsepower requirements by test."

From these quotations the chaotic condition this motorization of machine tools is in can be seen. In further substantiation of these remarks, a chart was taken from a Moline Hole Hog used in finish-reaming cylinder blocks. The machine was equipped with a 15-hp. motor, whereas less than 5 hp. was required for the operation. In one plant with which the author is familiar, 235 tests were made upon motor-driven tools and group drives having a total of 2100 motor hp. connected. After these tests were made, reductions to the amount of 1100 hp. were made in connected motor horsepower, some of the lineshafts of the groups showing a friction load of 56 per cent.

Fig. 5 shows a case of under-motorization of a Rockford drill. a 5-hp. motor having been originally installed, but upon changing the machine over to another operation, this was determined to be too small and a 7.5 hp. motor was found to be required.

Group Drive

The question of individual drive for machine tools or of group drive for them provides many arguments for and against each system. There is no question that smaller total motor horsepower is required for group drive than for individual-motor drive. Take as an example a battery of ten polishing stands which can be driven by a 20-hp. motor as a group, but if individually driven a 5-hp. motor is required for each stand to take care of the peak load which occur at times.

Shop-layout and working conditions must be considered in addition to the question of how often machines have to be rearranged, together with the comparative cost of shafting installation in comparison with electric wiring before determining which class of installation is to be used.

Flywheels

In recent years the application of flywheels upon intermittent drives, such as board drop hammers and polishing stands, seems to have been forgotten, also the flywheel effect of the old cast-iron pulleys in comparison with wood and pressed steel.

The author assisted in designing the shafting equipment for a large forge shop about four years ago and used a 5000-lb. split flywheel as a receiving pulley from the motors. This has eliminated belt troubles, and in fact the majority of the original belts are still in operation on both the motors and the hammers.

From the foregoing remarks it is hoped that the author has cited sufficient examples to show the necessity for management taking more interest in this question of power transmission and the appointment of a capable engineer to supervise it. He has not touched upon the economies which can be effected in the boiler room, power house, or wiring systems, all of which contain as great or possibly greater opportunities for economy than does the manufacturing division of a plant.

Discussion

Claude O. Streeter.[3] The paper brings out many valuable points which, if given consideration, will unquestionably result in economies. However, there are some points brought up which should be considered a little more carefully in regard to their practicability.

Construction of Leather Belting

In discussing this point the writer has in mind a commercial and not a special product. Consequently, the variation of plus or minus $^1/_{64}$ in. is not practical due to the fact that the natural variation in thickness of a piece of leather is $^4/_{64}$ in. In other words a belting strip which is $^8/_{64}$ in. thick on the shoulder end will be $^{12}/_{64}$ in. thick on the butt end, and approximately $^{10}/_{64}$ in. thick mid-way between these two points.

In the construction of leather belts it is necessary that joints be broken, which will result in the shoulder end which is $^8/_{64}$ in. thick being placed at this mid-way point which is $^{10}/_{64}$ in. thick, thus making the thickness at this point $^{18}/_{64}$ in. This will also bring the $^{12}/_{64}$ in. butt end opposite the $^{10}/_{64}$ in. middle point in the other ply thus making a $^{22}/_{64}$ in. total thickness, thereby making $^4/_{64}$ in. natural variation mentioned above.

This construction discussion pertains to double belting.

Of course this thickness variation can be reduced by the expedient of splitting the heavy sections or shimming the light sections, but when it is considered that the splitting would be done on the flesh side, and further consider that this flesh side contains approximately 50 per cent of the tensile strength of the whole piece, the fallacy of splitting off this strength, which would result in excessive stretch, is apparent.

Then again, when the size of the shim is considered which would be necessary to build up the light section and further consider the undesirability of shims in double belts, one is again impressed with the fact that this is impractical.

The maximum length of 50 in. specified is also economically unwise due to the fact that a belt bend which is 48 in. long on the backbone will be 54 to 56 in. long six to eight inches from this backbone due to the natural contour of the butt end of the hide. This extra length of material is very excellent stock, consequently the fallacy of cutting it off with the resultant waste is apparent.

It would seem to be much better if the maximum length were specified as 54 in. and the minimum length as 36 in. including laps, for single belts. For double belts the minimum should be 20 in. long for one-eighth the total pieces used, no two of these short strips to come consecutively. This short length in double belting is absolutely necessary due to the necessity for breaking joints as previously mentioned, and the natural variation which will occur in the length of belting strips.

In regard to leveling, to provide at least 90 per cent of contact it is assumed that this means leveling of the finished belt, and such being the case this leveling would occur on the grain or smooth surface. When it is considered that this grain surface has a high tractive value one is impressed with the fact that anything which removes this surface will detract from that value, and consequently is undesirable.

The contact of the belt surface on the pulley faces when the belt is new is not complete due to the fact that the belt has not broken in on the drive, and the various fibers have not become equally compressed. The result is that the surface of a new belt has a mottled appearance, but after the belt has run for a few days this mottled appearance disappears, and the belt takes on a uniform surface finish.

All know that when new, a leather belt is at its poorest as a

[3] Mechanical Engineer, Engineering Dept., Graton and Knight, Worcester, Mass.

power transmitter and also that it improves with age; consequently strong consideration should be given against the removal of the grain surface of belting for commercial purposes. Special belting is another consideration entirely, but as this evidently is not a point to be considered in connection with this paper at this time no discussion of it seems necessary or advsiable.

Inspection

The point raised here is a very excellent one, and if people who think they are buying to a specification would merely read this one paragraph they would immediately appreciate how valuable their specification is to them. As a matter of fact of the thousands of leather-belting specifications which are used for obtaining bids throughout the country, there are very few by which the goods received are checked up for the simple reason that the people using them have no facilities for this checking.

This practice works an extreme hardship on the leather-belting manufacturer who bids to a specification with the intention of supplying goods which will meet the specification due to the fact that the small unscrupulous concern, knowing that the specification is not enforced, puts in a price which he knows will be acceptable to the concern buying, and plans to furnish the belting in accordance with that price.

The comments in regard to determination of correct sizes of belting are particularly apropos, and the mechanism described for this work is not basically new as it has been used by many investigators. The one feature about it which is new is the use of the high-lift truck for the installation of the motor. The usual method is to have a portable motor which can be fastened to the floor very rigidly.

One thing about the high-lift truck equipment is that it would be particularly difficult to establish and maintain proper alignment, and it would seem that a considerable amount of difficulty would be experienced from vibration, particularly when the platform was at a comparatively high level.

The statement in regard to the installation of fabric belting of reduced width on gear shapers replacing double belts is particularly interesting, but the fact must not be lost sight of that first cost is not the whole story when leather belting is replaced with fabric belting. The low transmitting efficiency of the fabric belt may readily eat up, in power and production loss, more than could be saved in the purchase price. This statement in regard to the fabric belting cannot be termed "sour grapes" on the writer's part as his company manufactures and sells both fabric and leather belting.

The comments in regard to high tensions are particularly well taken, but many times belts are roped on to drives because of the ease of this method of installation of endless belts, particularly on overhead drives, and while they will be tight when first roped on, this is only a temporary condition, and is soon relieved by the stretch and elasticity in the belt.

The real meat in this statement is the fact that belts should be properly proportioned to the work to be done on any drive, and then power transmission will be economical with difficulties reduced to an absolute minimum.

The tension of 190 lb. mentioned is practical, but if anything it is a little bit on the high side when it is considered that 190 lb. per sq. in. of cross section will equal approximately 50 lb. per in. of width per strand for a total initial tension of 100 lb. for a single belt. The use of a rider belt is a common one and seems to be open to no comment.

The comments on the motorization of machine tools are most certainly extremely well taken. The one possible difficulty to be considered is the fact that machine tools have a habit of changing hands. Consequently, if the tool is not motored to maximum capacity in the plant it was originally purchased for, because the work does not call for it, the next purchaser of this tool may be in considerable difficulty because his machine is under-motored due to the heavier type of work he is doing. This, of course, can be overcome by each purchaser of this tool endeavoring to get the manufacturers to ascertain as to what power is required for his particular work. This will be easy enough where the used tool is purchased from its original manufacturer, but probably would be deemed a hardship by that same manufacturer if it was purchased from some other source. This may not be a particularly vital consideration, but one which it would do no harm to consider.

The comments on group drives and fly wheels are very interesting and contain considerable food for thought, and if more thought was given, particularly to the group drive consideration, there would be less individual motor equipment used than is the case at the present time. In other words, industry seems to have gone individual-motor crazy, and while there is a possibility of being equally ridiculous on the group-drive basis this is rather remote, but should not be lost sight of.

MSP-52-10

Test Code for High-Speed Steel for Turning Tools

Report of Sub-Committee "D" on Properties of Materials[1] of the A.S.M.E. Special Research Committee on Cutting of Metals

PREPARATION of a test code for tool steels brings into consideration the composition and the heat treatment of the tool steel to be tested as well as the characteristics of the material to be cut by the test tools and the general conditions governing the test.

The American Society for Testing Materials in 1916 initiated the preparation of tool-steel specifications by Committee A-1 on Steel appointing Sub-Committee XIV on Tool Steel. The early meetings of this sub-committee showed that there were no generally accepted methods of chemical analysis for tool steels. Therefore, Committee XII on Methods of Chemical Analysis, of Committee A-1, was requested to develop standard methods of analysis applicable to tool steels. The following have been prepared:

Serial designation A 33-24	Standard Methods of Chemical Analysis of Plain Carbon Steel
Serial designation A 55-24	Standard Methods of Chemical Analysis of Alloy Steels.

The committee discussions showed that there was a very large number of tool-steel compositions employed. One member stated that his company employed over 2000; that there was a very wide range of applications for tool steels for cutting, for example, lathe and planer tools, milling-machine tools, drills, taps and dies, etc., tools for woodworking and other industries, and that the use of a specific tool-steel composition was not uniform throughout the United States. It was manifestly impossible to write a specification which would state a specific composition. Therefore, it was decided to write each specification to permit the specific composition being made a matter of agreement between the purchaser and vendor. A table was incorporated in the specification establishing permissible variations from the agreed upon composition. For example, the following table is applicable to carbon tool steels:

		Permissible variation, per cent Over	Under
Carbon		0.05	0.05
Manganese	when under 1.00	0.10	0.10
	when over 1.00	0.20	0.20
Phosphorus		0.005	..
Sulphur		0.005	..
Silicon		0.15	0.15

Other elements as agreed.

To facilitate inspection a table of permissible dimensional tolerances was incorporated in the specification. Methods for marking the tool steel, for preparing it for shipment, and for obtaining the sample for chemical analysis are described in the specifications. In case of dispute as to chemical composition the standard methods of chemical analysis previously referred to are to be used. The following specifications have been prepared:

Serial designation A 71-26	Standard Specifications for Carbon Tool Steel
Serial designation A 92-26	Standard Specifications for High-Speed Tool Steel
Serial designation A 115-28	Standard Specifications for Alloy Tool Steel.

These specifications apply to tool steels in general use. The sub-committee is prepared to assist in any research work which may be of service in developing test codes for tool steels.

The American Society for Steel Treating has been developing practices for heat treatment of steels, including tool steels. In view of the importance of proper heat treatment for tool steels the recommended practices developed by that Society have been appended to the carbon tool-steel and to the high-speed tool-steel specifications, but on account of the wide range of permissible compositions covered by the alloy tool-steel specifications reference only is made to the recommended heat-treatment practices developed from time to time.

The American Society of Mechanical Engineers in 1923 appointed a special research committee for cutting of metals to consider, among other subjects, the cutting performance of tool steels. The work of this committee is closely related to that of the corresponding committees in the two societies mentioned.

A review of the applications of tool steels resulted in the selection of high-speed tool steel as the subject for the first test code. Other test codes can be developed as soon as the essential characteristics of the high-speed tool-steel test code have been definitely determined. The type of test code will depend upon whether or not the tests are to be conducted in accordance with laboratory procedure or in accordance with the usual facilities available in a machine shop. A tentative test code has therefore been prepared to permit the omission of some of the test apparatus, and the test computations indicated in Fig. 1 can be reduced to those required by the experimenter.

The tentative test code is presented at this time with a view to obtaining constructive criticisms, to the end that a satisfactory test code may be developed later.

A.S.M.E. Tentative Test Code for High-Speed Tool Steel

Code. This test code is applicable to high-speed tool steel intended for manufacture of lathe and planer tools.

Steel Specifications. The material shall be in general accordance with the Standard Specifications for High-Speed Tool Steel, A92-26, prepared by The American Society for Testing Materials.

Sample. The sample bar for test tools shall be $\frac{1}{2}$ in. $\times$ 1 in. $\times$ 72 in. long. The bar shall be cut into five approximately equal lengths for test tools and identification number stamped on each length.

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[1] The personnel of this Sub-Committee consists of: L. H. Kenney, *Chairman*, Mech. Engr. U. S. Navy Yard, Philadelphia, Pa.; H. J. French, Metallurgist, International Nickel Co., Bayonne, N. J.; J. O. Keller, Professor, Pennsylvania State College, State College, Pa., and W. W. Nichols (ex-officio), Detroit, Mich., *Chairman*, A.S.M.E. Special Research Committee on Cutting of Metals.

Contributed by the A.S.M.E. Special Research Committee on the Cutting of Metals and presented at the Annual Meeting, New York, N. Y., Dec. 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

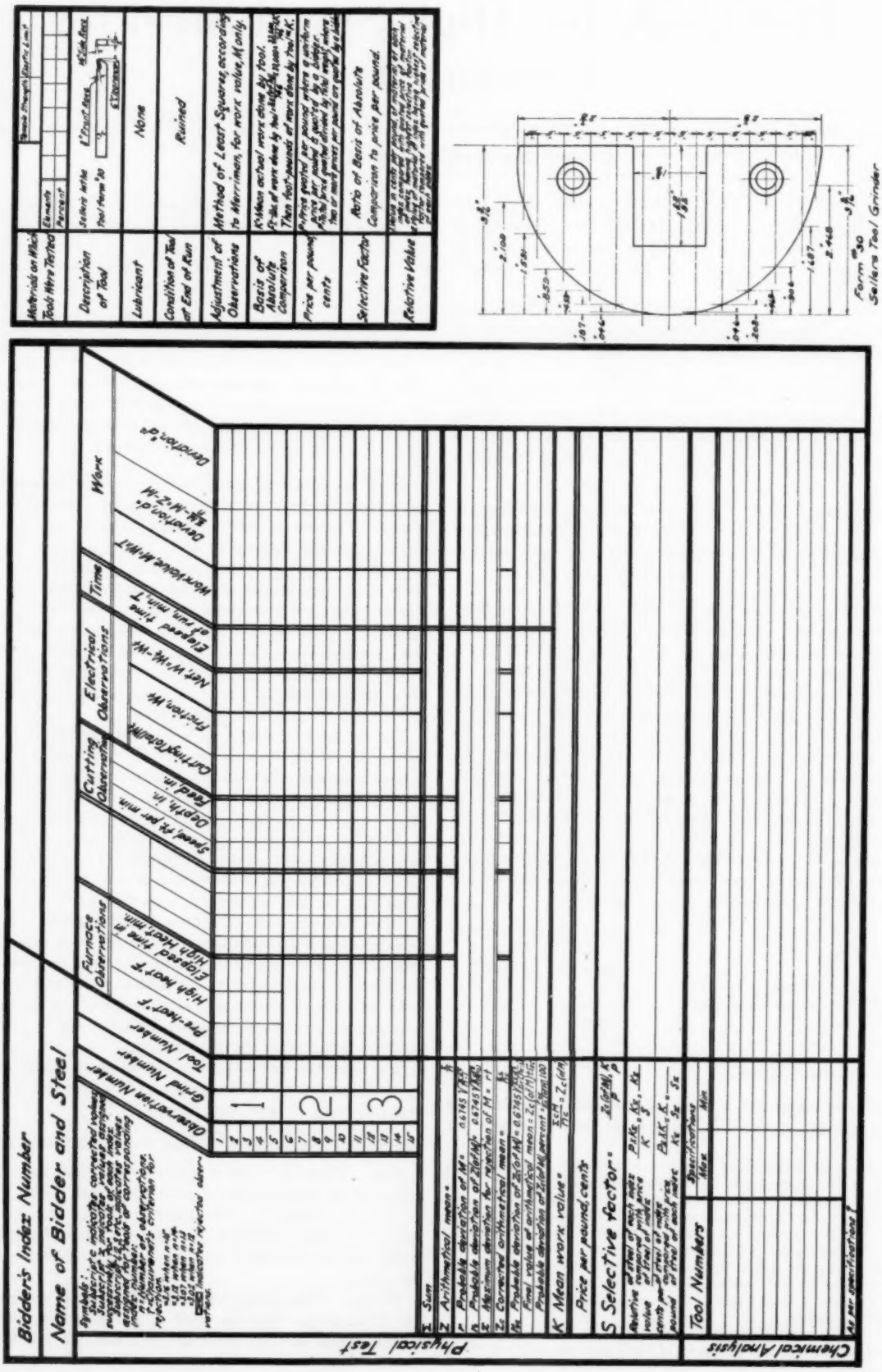


FIG. 1 LOG FORM FOR DATA

Grinding. The test tools shall be ground without forging and previous to heat treatment to approximately the specified tool form, Fig. 1. After heat treatment and after each failure on the test cut, the tools shall be ground to the specified tool form, care being taken to remove the material affected by the previous cut. It is essential that this work be done carefully and accurately.

Heat Treatment. The heat treatment for the test tools shall be in general accordance with the Recommended Practice for Heat Treatment prepared by The American Society for Steel Treating and appended to the A.S.T.M. Standard Specifications referred to.

Test Forging. The nickel-steel forging on which the sample tools are to be tested should be originally approximately 2 ft. in diameter by 10 ft. long. The chemical composition shall be approximately as follows:

Carbon, per cent	0.30–0.40
Manganese, per cent	0.50–0.80
Phosphorus, per cent	not over 0.040
Sulphur, per cent	not over 0.045
Nickel, per cent	3.25–3.75

The physical characteristics shall be approximately as follows:

Tensile strength, pounds	95,000
Proportional limit, pounds	65,000
Elongation in 2 in., longitudinal per cent	21
Reduction in area, longitudinal per cent	45
Brinell hardness	190
Rockwell hardness	C19

Test Cut. The test tools are to be subjected to a cutting test in a lathe on the test forging, the depth of the cut being $^3/_{16}$ in., the feed 0.044 in. per rev., and the cutting speed about 56 ft. per min. The test speed selected, however, should give for a representative type of tool steel a cutting life of from 15 to 20 minutes. The cutting speed so selected shall be standard for the test.

Work Done by Cutting Tool. A graphic wattmeter may be installed to determine the motor input when the lathe is operating with and without cut, or any equivalent means of measuring the power may be used. The difference in power required when the lathe is operating with and without cut is a measure of the work done by the test tool in cutting the test forging.

Tabulation of Data. The observed data may be recorded on the log form, Fig. 1 on page 116, and the indicated computations made.

Selective Factor. The selective factor, Appendix No. 1, is the ratio of the work done to the cost per pound of the material under test. The factor serves as a basis for comparison when several samples are tested.

Discussion

O. W. Boston.[2] The writer has been an interested observer of the development of this tentative test code for the past several years. He believes that the testing of high-speed steels is done in a large number of plants, but under many different conditions and by different methods. While there may be some objections to certain phases of this test code, it will start people thinking along the line of uniformity and standardization and may eventually lead to a test code which will be satisfactory to the majority of users of high-speed-steel tools. This test code may have to be made more general, as was the case as reported by the author regarding "standard methods of chemical analyses," "standard specifications for high-speed-steel tools," and the "recommended practice for heat-treating high-speed-steel tools." Only a few years ago it was thought impossible to formulate such standards.

There may be some questions raised as to the exact nature of the work which the high-speed-steel turning tool is to do; whether it is to be used for finishing or light cuts, medium duty, heavy duty, or even so-called super-heavy duty. This might be made a part of the specifications, or several sizes of standardized cuts may be specified, better to meet the particular practical application. In other words, a tool which is to be used for taking cuts between $^1/_2$ and 1 in. in depth and, say, $^1/_8$ in. feed might prove inferior after receiving a favorable rating with test cuts $^3/_{16}$ in. in depth and 0.044 in. feed per revolution as specified.

The Sellers lathe tool, form No. 30, has been specified on a shank $^1/_2$ in. wide by 1 in. deep. It would seem desirable to have the details of this shape, or whatever shape is most desirable, specified more in detail, as many people wishing to conform with the test code might have to grind tools on grinders other than of the Sellers make. Perhaps a simpler tool shape could be used which could be ground quicker and more accurately on any grinder. The test log is of a material and condition that might be hard for many to obtain. The size is large for most plants to handle conveniently, or it may be even too large for any lathe available in many of the plants. The size, however, is of little importance so long as the diameter is sufficient to make the reduction in cutting speed, due to successive cuts, inappreciable.

The work done by the cutting tool, as determined by the wattmeter, is really a measure of machinability of the test log rather than any indication of the property of the tool material, as long as the cutting tool remains sharp and of the same geometric shape. This power consumption does not appear, therefore, to be of primary importance except as an indication of the time of tool failure, although the writer is of the opinion that all possible information which can be collected in such a test should be recorded.

The writer hopes that this test code will be given serious thought by the makers and users of tool steels and that the subcommittee may be advised as to desirable changes or additions, so that it may eventually be developed into a useful standard.

Closure

Mr. Kenney. The preparation of a Test Code for High-Speed-Tool Steel is complicated by the number of tool-steel compositions, heat treatments of these tool steels, geometric shapes of the cutting edges of the tools, coolants or lubricants, materials to be cut, types of machines in which the tools may be used, types of cutting requirements, and so on.

It may be possible in time to develop suitable laboratory testing machines which will determine the essential characteristics of cutting tools for their principal applications. It follows that a satisfactory method must be developed for comparing the performance of the tools in the shops with the laboratory tests. Not until this is done will it be possible to predict with a satisfactory degree of accuracy the shop performance of cutting tools based on laboratory data. It should be possible to develop laboratory testing machines and arrange for a number of independent investigations, the investigations to be so conducted that the data obtained will be readily comparable. With such a program it is believed that it will be possible in time to so revise the Tentative Test Code that it can be adopted as a "Standard Test Code for High-Speed Steel for Turning Tools."

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MSP-52-11

What Happens When Metal Is Cut

By ORLAN W. BOSTON,[1] ANN ARBOR, MICH.

The paper constitutes a valuable contribution to research and a check in some instances upon the conclusions of other authors. This study is confined mainly to deformation as seen on the exterior of the metal. It is first of several steps which may include use of the X-ray and the moving picture to reveal more exactly what is taking place as the cutting tool advances into the metal.



IN reviewing the great amount of work done with metal-cutting tools and the lack of definite information available for use in connection with machine-tool design (Ref. 3), Mr. A. L. De Leeuw listed eleven questions which should be answered in a scientific manner. These questions are as follows:

(*a*) When we turn up a narrow disk by means of a square-nosed turning tool of which the width is greater than the width of the disk, is the action of removing the chip purely a matter of tension? Or, if not, what is it?

(*b*) Does the front end of the tool have any function at all?

(*c*) How far from the edge of the tool is the point where the chip strikes the tool?

(*d*) If the action is purely a matter of pull, and the chip does not strike the top of the tool at the cutting point, but some distance farther back, then is it necessary that the cutting edge of the tool be sharp?

(*e*) What is the nature of the lamination of the chip?

(*f*) How much power is required for the actual removal of the chip, for the friction between chip and tool, and how much for laminating the chip?

(*g*) What would be the best shape for such a turning tool for this particular turning operation?

(*h*) How does the amount of power vary with the various angles of the tool?

(*i*) If the turning operation is not as simple as the one assumed in question (*a*)—if, for instance, there is a side feed, such as in ordinary shaft-turning operations—how is the cutting action modified by this side feed?

(*j*) If the chip is removed by the action of the top of the tool—that is, if the front of the tool has no function—then what determines the nature of the finish of a cut?

(*k*) In what relation does the power required for the side feed stand to the power required for the actual removal of the chip?

The fact that these questions have been listed as subjects about which definite information is lacking indicates the complexity of the subject of metal cutting and chip formation. To this mystery was added the subject of cutting fluids, which complicates it still more. De Leeuw further indicated that many more questions might be asked after these were answered.

It is for the purpose of being able to add to the understanding of the subject of metal cutting that the following study is made.

Nature of the Investigation

After completing a series of experiments dealing with tool shape and chip size a number of years ago (Ref. 21), it occurred to the author that information of a still more elementary nature was needed. The equipment used in the investigation consisted of a large planer on which was mounted a specially designed dynamometer, so that the force on the tool in the direction of cut could be measured. This equipment seemed to be ideal for a set-up to photograph, under various magnifications, the side of the chip and tool during the process of cutting. A tool of the end-cutting type was used to remove a chip from the top of a ridge. This ridge was prepared to be $^1/_4$ in. thick, and its face was carefully ground and polished. The side of the tool and the face of the work were in approximately the same vertical plane.

It seemed desirable to take these photographs at a magnification greater than unity. The magnifications finally used were the result of trial and error. It was found that any magnification between 50 and 100 was sufficiently clear to show the deformation of the metal. The lower magnifications, however, did not bring out all desired details, and the higher ones introduced difficulties of focusing on all particles in the field due to the deformation from the vertical plane in front of the objective. Definite information which would serve as a guide in making the set-up seemed lacking.

Equipment Used in the Tests

The set-up, consisting of a planer on which is mounted the work, tool, microscope, and camera, is shown in Fig. 1. The tube of the metallurgical microscope was mounted in a specially constructed saddle so as to maintain proper alignment with the camera shutter center, but permitted adjustment on the saddle, to and from the work, as different objectives were employed. The objective and eyepiece on the microscope could be changed to suit conditions, although the majority of the pictures were taken with a 16-mm. objective and a $7^1/_2$X eyepiece, which in themselves would give 75 magnifications. A 9 by 12 cm. camera was placed on a saddle back of the microscope with the shutter of the camera close to the eyepiece. A short space was permitted between the shutter and eyepiece to permit slight adjustment of the microscope barrel for the purpose of focusing. A telescopic tube bridged this gap.

The magnification resulting from the microscope objective and eyepiece was modified by the location of the plate of the camera. It was found that, to secure pictures having the same magnification as indicated by the microscope set-up, the plate

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Contributed by the Machine Shop Practice Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

of the camera had to be approximatelv $12^1/_2$ in. from the eyepiece. With the plates located at $12^5/_8$ in., the actual magnification of the pictures, as recorded, is 81.25 times. By moving the plate holder toward the microscope eyepiece, the magnification is reduced; by moving it away from the eyepiece, the magnification is increased. This distance of $12^5/_8$ in. between the eyepiece and the plate was larger than that permitted by the camera bellows, so that the shutter of the camera was mounted in a specially constructed frame located back of and in line with the eyepiece. A second frame was constructed to carry the plates. These special frames were then joined by a separate bellows taken from a lantern-slide projector. The camera lens was removed from the set-up.

At first considerable trouble was encountered by lack of proper illumination of the tool and work. Finally, a small 4.5-ampere arc light using $^5/_{16}$-in. carbons was installed, as shown in Fig. 1. It was attached to the tool holder directly over the microscope, so that its illumination was projected on the work at an angle of 45 deg. from the vertical. A yellow filter was interposed between the light and the work. All photographs were taken after dark with lights out. In this condition the image could be focused carefully on the ground glass of the camera before the plate was substituted. A 4 in. diameter hand magnifying glass was used to obtain definiteness on the ground-glass image in focusing.

With the set-up as described, observations could be made on the ground glass during the process of cutting—that is, while the work was being moved into the tool. This set-up was such that the camera could be removed conveniently so that observations could be made directly through the microscope. Many observations through the microscope or on the ground glass have been made. Only specific instances, however, have been photographed.

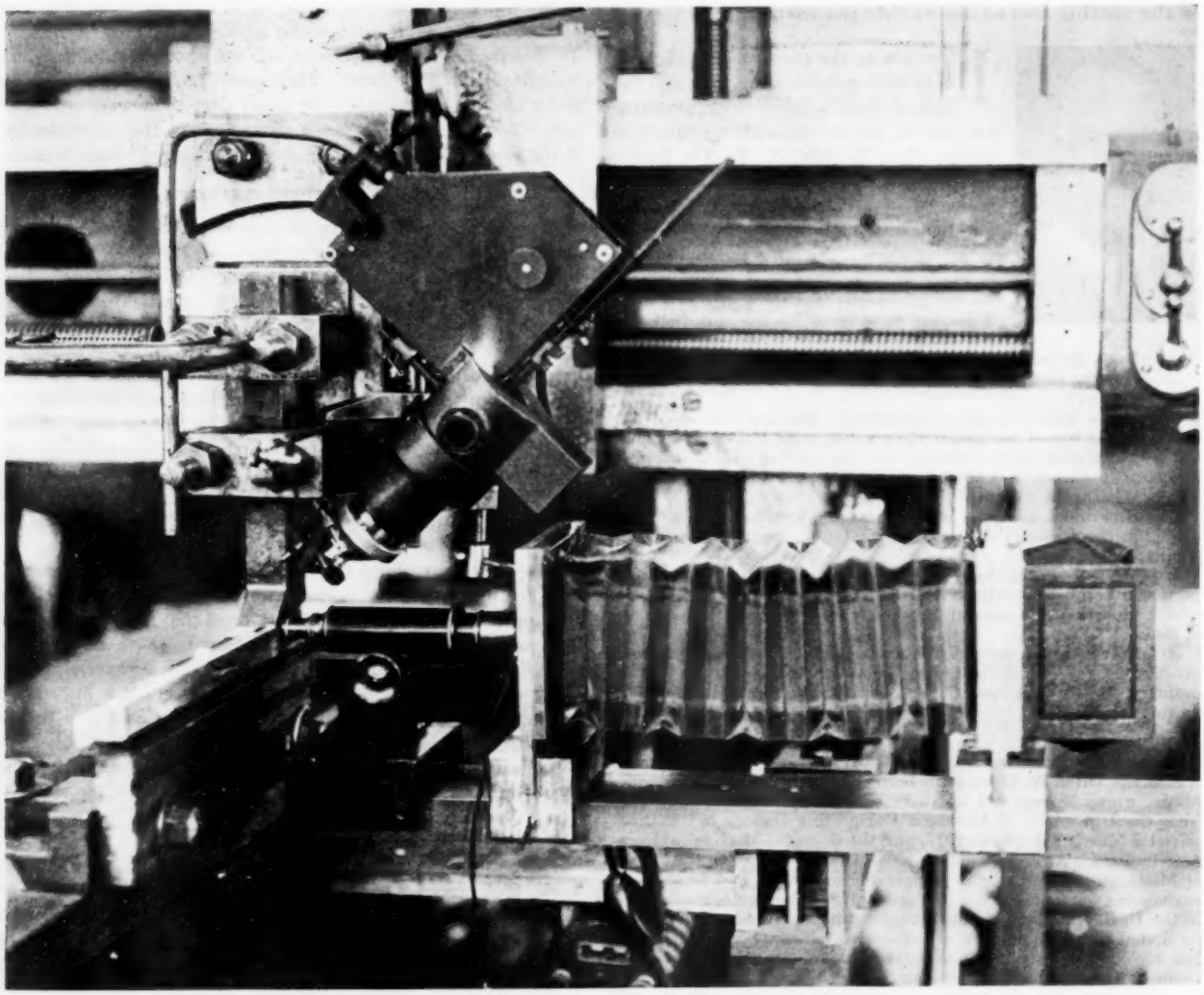


FIG. 1 THE MICROSCOPE AND CAMERA SET-UP ON THE PLANER

A very desirable feature of the set-up, as used, is the possibility of making observations while the tool is cutting continuously, but of course at a very slow speed. The driving wheel of the planer was turned by hand, and the movement of the planer table was recorded on a dial indicator attached to the bed at the end of the table. The operator, in turning the drive wheel, could observe the readings of the dial gage and report continuously to the one making the observations the distance traveled. By this means a great amount of information has been obtained as to the exact formation of the various sections of a chip which might be entirely overlooked in the type of work

where pictures are taken intermittently. In other words, the illustrations recorded in this paper show the chip and tool at a given instant, but in every case observations have been made of the continuous movement of the metal during the formation of the chip from one stage to another—that is, from one picture to another.

Arrangements also have been made for locating a moving-picture machine back of the microscope, so that moving pictures instead of still pictures can be taken to record this continuous cutting process. Some moving-picture films have been prepared, but the results are not altogether satisfactory due to difficulties of illumination and of keeping the object continuously in focus. The scope of this paper is limited to the stationary pictures and the results of observations leading up to these stationary pictures.



Fig. 2 Tool at Zero



Fig. 4 Tool at +0.010 In.



Fig. 3 Tool at +0.005 In.



Fig. 5 Tool at +0.015 In.

FIGS. 2, 3, 4, AND 5 SUCCESSIVE STEPS IN FORMATION OF A CHIP
(Cast-aluminum alloy No. Al-12; depth of cut, 0.010 in.; 15-deg. front-rake tool; actual magnification 81.)

The Tools Used. The tools used in this study were forged

TABLE 1 CHEMICAL ANALYSIS OF MATERIALS CUT

Material	Bar No.	Chemical analysis in per cent									
		C	Mn	P	S	Si	Cu	Zn	Tin	Pb	Al
Carbon open-hearth steel (0.15%)	IIII	0.15	0.24	0.014	0.029	0.13	...	...	...	...	...
Screw-stock steel	414	0.10	0.66	0.098	0.195	..	...	...	...	...	...
Cast iron ($1^1/_8$-in. rod)	11–1	0.53(*a*)	0.52	0.32	0.056	2.26	...	...	...	...	...
Cast aluminum (1 in. sq. Al-12)	12	...	..	...	...	..	8	...	...	...	91(*b*)
Rolled sheet brass	26	...	..	...	...	..	61.34	37.18	0.034	1.44	...
High-speed brass (leaded)	X	...	..	...	...	..	62	35	...	3	...

(*a*) Combined
(*b*) 1% of impurities

from 1 in. by 2 in. high-speed-steel bars, so that the cutting edge and face of the tool projected beyond the body of the bar. They were ground and lapped to shape so as to present a smooth surface and a keen cutting edge. They were of the end cutting type, similar to a cut-off tool. The clearance angle in each case was 4 deg. The front rake angle, however, was varied to suit conditions of the study and is recorded in the individual tests.

The Feeds and Speeds. In these experiments the feed was

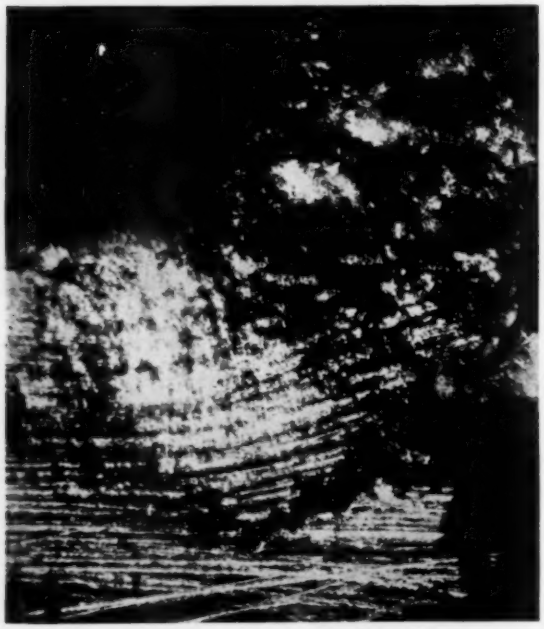


FIG. 6 SHOWING TEAR IN ALUMINUM
(Conditions same as in Figs. 2 to 5.)

obtained by lowering the tool vertically after each chip was removed. The amount of the feed was read from a dial indicator arranged as shown in Fig. 1. Many of these cuts were taken with a 0.005 in. depth, or feed, and some were taken at 0.010 or 0.020 in., as recorded in the individual study.

The speeds used varied considerably. All speeds in this study were obtained by driving the planer by hand so that occasionally a speed of several feet per minute was developed for observation purposes, but when pictures were taken the chip recorded was actually formed at a very slow speed, so that the table could be moved a few thousandths of an inch to the next desirable chip condition.

MATERIALS CUT

Six different materials were studied in this investigation. The chemical analysis of each is shown in Table 1. These materials are as follows:

(*a*) An 0.15 per cent carbon open-hearth steel, bar No. IIII. This bar was fully annealed and produced in a size 4 in. by 6 in. by 4 ft. In tension this steel had a yield point of 20,900 lb. per sq. in. Its ultimate strength was 52,000 lb. per sq. in.; its reduction of area was 65 per cent, and its elongation 40 per cent in 2 in. gage length. In shear the ultimate strength was 39,400 lb. per sq. in. The hardness values were: Brinell, 102; scleroscope, 21; and Rockwell, 45 ($^1/_{16}$ in. diameter ball).

(*b*) A cold-drawn super free-cutting steel for screw-machine work, bar No. 414, 1.078 in. in diameter. This material had an ultimate tensile strength of 86,100 lb. per sq. in. Its Brinell hardness taken on the interior was 207, the Rockwell B scale was 93, and the scleroscope 29.

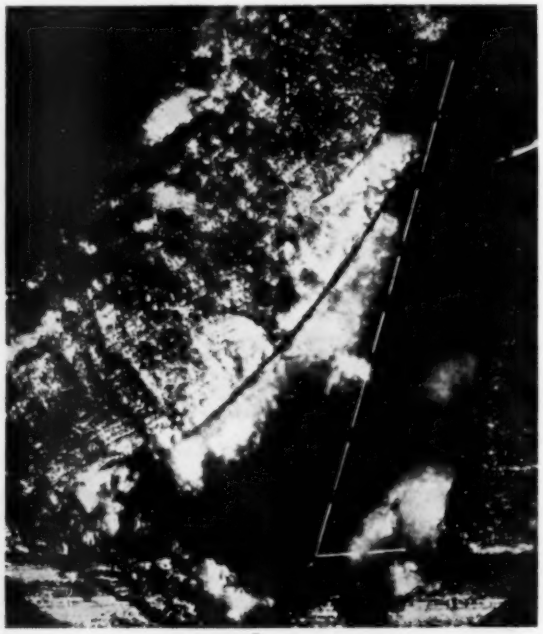


FIG. 7 SHOWING "BUILT UP" NOSE IN ALUMINUM
(Conditions same as in Figs. 2 to 5.)

(*c*) A cast-iron bar No. 11–1, $1^1/_8$ in. round. Its Brinell hardness was 207.

(*d*) No. 12 cast aluminum, 1 in. square, bar Al 12. Its yield point in tension was 18,455 lb. per sq. in.; its ultimate strength was 19,046; its reduction of area was 6 per cent, and the per cent elongation in 2 in. was 1.6.

Its Brinell hardness, with 500-kg. load and 10-mm. ball, was 63, its Rockwell B scale hardness was 77, and its scleroscope hardness was 14.

(*e*) A non-leaded rolled sheet brass $^1/_2$ in. thick, bar No. 26. In tension the yield point was 35,000 lb. per sq. in., ultimate strength 38,000 lb. per sq. in., reduction of area 32 per cent, and elongation in 2 in., 31 per cent. Its shear strength was 35,600 lb. per sq. in. The Brinell hardness for 500-kg. load and 10-mm. ball was 109, and Rockwell B scale hardness was 102, and the scleroscope hardness was 24.

(*f*) A high-speed free-cutting brass (leaded) $^1/_2$ in. square, bar X. The ultimate shear strength was 37,100 lb. per sq. in. The Brinell hardness with 500-kg. load and 10-mm. ball was 105, the Rockwell B scale hardness was 100.5, and the scleroscope hardness was 40–36.

Photomicrographs and various machinability data are shown for these metals in a paper, "Methods of Tests for Machinability of Metals in General, With Results," *Trans. A.S.S.T.*, Vol. 16, Nov., 1929, p. 659.

Observations

Cutting Aluminum. With a set-up of the microscope having a 16-mm. objective and a 7.5-hyperplane eyepiece, and with the camera plate located 12⅝ in. from the eyepiece giving an actual magnification of 81, the observations recorded in Figs. 2–7, inclusive, were taken. A cast-aluminum alloy bar (No. Al-12) was used. A tool having a front-rake angle of 15 deg., which was ground and lapped to give a smooth surface and a keen edge, was used.

A cut having a depth or chip thickness of 0.010 in. was started, and after the tool had moved slowly into the work 0.062 in. it was stopped. The resulting condition is shown in Fig. 2. This position illustrates the instant at which the large section of the chip was sheared loose from the main portion of the metal along the shearing plane extending from the tool point upward



Fig. 8 Tool at Zero

to the left at an angle of approximately 29 deg. from the horizontal, or 76 deg. from the tool face. As the point of the tool advances it gradually accumulates a second chip section similar to the one just sheared off. Repeated observations of the formation of similar sections showed them to vary in size. It was noted that when kerosene was applied to the tool and the work the chip sections were approximately of the same size and that one would be sheared off every 0.023 in. travel of the tool. It can be said that this so-called shearing-off still leaves the chip section attached firmly to the adjacent sections. In other words, there is a continuous chip built up of various sized sections.

Fig. 3 shows the condition of the metal after the tool has been advanced 0.005 in. from that position shown in Fig. 2. In this position the tool point is just beginning to gather up material on its nose. This rotates the last section of chip removed and changes the angle at which the section sheared off from 76 deg. to approximately 90 deg. to the tool face. In Fig. 4 is shown the condition of the metal after the tool has been advanced an additional 0.005 in., which is 0.010 in. advance of that position shown in Fig. 2. Continuous observation between the positions shown in Fig. 3 and Fig. 4 as the tool advanced shows that the section of the chip being formed is built up of a large number of small laminations caused by the tearing and shearing of the metal along the plane of shear, which is approximately



Fig. 9 Tool at +0.005 In.

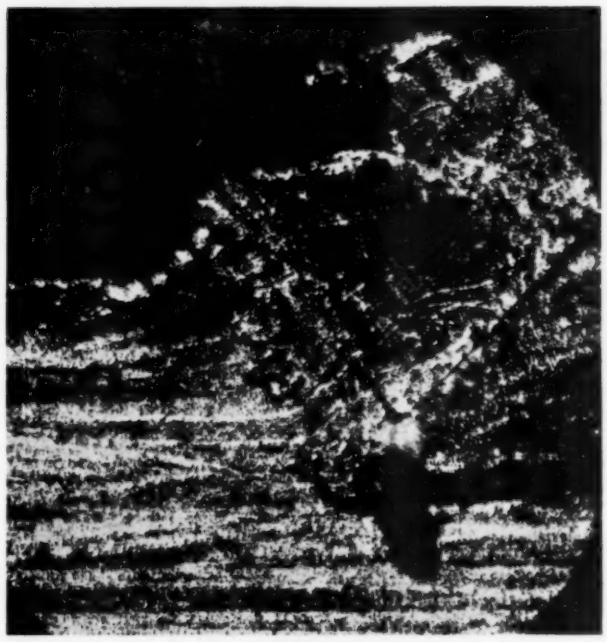


Fig. 10 Tool at +0.010 In.

Figs. 8, 9, and 10 Successive Steps in Formation of a Chip (Cast-aluminum alloy No. 12; depth of cut, 0.010 in.; 45-deg. front-rake tool; actual magnification 110.)

29 deg. to the horizontal. In Fig. 5 the position of the tool is shown after it has been advanced an additional 0.005 in., making a total of 0.015 in. in advance of the position shown in Fig. 2. The section of the chip on the point of the tool shown in Fig. 5

is nearly ready to be sheared as a unit free from the main portion of the material.

In taking preliminary cuts of approximately 0.010 in. in depth on the ridge of the aluminum specimen to prepare it for the



Fig. 11 Tool at +0.015 In.



Fig. 12 Tool at +0.020 In.

0.010 in. depth of cut illustrated in Figs. 2 to 5, inclusive, certain observations were made as recorded in Fig. 6 and Fig. 7. The 15-deg. front-rake tool was started on a cut, and after advancing about $^3/_{16}$ in. along the ridge, it was noticed that a large piece of material ahead of the tool was being torn off by the usual "tear" principle. Fig. 6 shows this tear in advance of the tool point. It shows that the tear goes deeper than the tool point into the metal. This condition did not occur frequently. Whether it is due to some impurity in the metal or to a surface condition is not known.

At another place, in truing up the specimen it was noticed that a built-up portion appeared on the nose of the tool. This condition was duplicated several times, and was finally recorded as shown in Fig. 7, for which illustration the tool has been withdrawn to the right. On another cut the first $1^1/_2$ in. of tool travel showed conditions similar to those represented by Figs. 2 to 5, inclusive. The metal cut poorly, and the chips were formed in sections of unequal shape and size. In moving the tool forward farther to a travel of 2 in., the chip flow became



Fig. 13 Tool at +0.025 In.

FIGS. 11, 12, AND 13 SUCCESSIVE STEPS IN FORMATION OF A CHIP (Cast aluminum alloy No. 12; depth of cut, 0.010 in.; 45-deg. front-rake tool; actual magnification 110.)

smoother and more uniform. The large sections seemed to disappear or become broken up into smaller equal sections, presumably due to a built-up edge which began to appear. Moving the tool still further to a travel of $2^1/_2$ in., a built-up edge became more defined and larger and extended forward into the material in advance of the cutting edge. The slope of this built-up edge just above the point is 50 deg. from the vertical, indicating perhaps that a 50-deg. front-rake angle on the tool is ideal. In moving the tool still further, the chips were removed with less distortion and less defined laminations or shear lines. The metal on the edge of the cut was forced toward the microscope objective and obstructed the view so that this projected mass had to be removed with a scraper. After scraping, the false edge stood out sharply, as recorded in Fig. 7. This was after $3^1/_8$ in. of metal had been cut at a very slow speed. Better to show the false edge, the tool was backed out to the right, leaving the false edge connected with the chip and work. The length of this built-up edge ahead of the tool nose is actually only about 0.016 in. This is 50 per cent greater than the thickness of the chip being removed, however.

It is interesting to observe the slight distortion occurring on the under side of the chip as it rubs over the face of the false edge. From these observations it appears that the material from which the false edge is built is gathered by the point of the tool as it scrapes over the surface after the bulk of the chip has been removed because of the pressure on the face of the tool back of the cutting edge. Fig. 7 does not show clearly what has occurred at the extreme point of the false edge because of a small amount of the cut material which has been forced toward the camera, thereby hiding the nose point.

After the exposures shown in Figs. 2 to 7, inclusive, were taken, kerosene was applied to the tool point and work, and various observations were made through the microscope as the tool was advanced slowly. It was not possible to secure the built-up edge when kerosene was used. The chip itself was removed with less distortion than when cutting dry. It seemed to be made up of thin uniform sections, causing the chip to be more dense and regular than was found in dry cutting. It was possible to observe the oil as it advanced on the face of the work ahead of the tool and even ahead of the material being distorted. This flow of oil would stop when the tool was stopped and proceed uniformly ahead of the tool when it was advanced. It appeared to be drawn into the material of the chip, causing it to be thoroughly saturated and thereby lubricated. It was observed that, as the chip slid over the face of the tool, it seemed to be compressed and the kerosene was squeezed out.

Usually, high rake angles are recommended for the cutting of aluminum. Inasmuch as the front-rake angle of the built-up nose on the 15-deg. front-rake tool, as shown in Fig. 7, was about 50 deg., a 45-deg. tool was prepared and used, as illustrated in Figs. 8 to 13, inclusive. The same camera and microscope set-up was employed, as already described. The work was in a slightly different position, so that an actual magnification of 110 was obtained. The depth of cut was 0.010 in. Fig. 8 shows the 45-deg. tool after cutting a short distance on the cast-aluminum alloy. The position of the tool as indicated is at zero, which is as near to the position at which a section of the chip shears off as could be determined. The definite line of shear is seen extending from the point of the tool to the surface of the work on approximately a straight line which makes an angle with a horizontal of 30 deg. The angle of shear shown in Figs. 2 and 4 when a 15-deg. front-rake tool is used is also shown to be this same angle. In Fig. 9 the tool has been moved



Fig. 14 Tool at Zero



Fig. 15 Tool at +0.024 In.



Fig. 16 Tool at +0.030 In.

FIGS. 14, 15, AND 16 SUCCESSIVE STEPS IN FORMATION OF A CHIP
(Free-cutting screw-stock brass, bar X; depth of cut, 0.005 in.; 15-deg. front-rake tool; actual magnification 100.)

to the left a distance of 0.005 in. from the position shown in Fig. 8. New shear lines are shown extending from the point of the tool to the surface of the material on approximately this same 29- or 30-deg. angle. In Fig. 10, where the tool is shown advanced an additional 0.005 in., making a total of 0.010-in. travel from the position shown in Fig. 8, the new section of chip is shown in formation. The line of shear along which the large section of the chip was moving in Fig. 8 is shown in Fig. 10, changed from 30 deg. from the horizontal to approximately 45 deg. from the horizontal, or at right-angles to the face of the tool. The material in the chip section being formed in Fig. 10, as viewed through the microscope, shows this section, as in previous observations, to be thoroughly broken up by shear and tension. It appears to be in a somewhat honeycombed condition, although this may be only on the surface. The bright spot at the tool point is a small particle of material extending from the field in focus toward the objective. The dark spot below this bright spot is a shadow. In Figs. 11, 12, and 13 the position of the tool is shown advanced in steps of 0.005 in. The section of the chip shown in Fig. 8, which has just been sheared off, is shown at the extreme upper part of the chip in Fig. 13. It has moved about 0.014 in. along the face of the tool from the tool point, or approximately 1.4 times the original depth of cut, while the tool has traveled horizontally 0.020 in. between Figs. 9 and 13. The thickness of chip is 35 per cent greater than the original depth of cut.

From general observations it was concluded at the time the pictures were taken that it was not possible to show a built-up nose on the cutting edge when the 45-deg. tool was used. Close examination of Figs. 12 and 13, however, shows that the front face of the tool is not a straight line, but rather a curve concave upward, indicating perhaps that there is a small layer of metal constituting a built-up edge on the point of the tool. This is shown clearly in Fig. 13. The built-up edge, however, is very small compared with that shown in Fig. 7 when the 15-deg. tool is used. It was noted at the end of each 12-in. cut with the 45-deg. tool in aluminum that a thin film of aluminum adhered to the tool face immediately back of the cutting edge. This may have been the built-up nose seen in Fig. 13. This does not seem to be a factor of high temperature, but rather one of pressure only. This film may increase friction so that the fully developed built-up edge results.

The chip, or built-up edge, along the face of the tool in Fig. 7



Fig. 17 Tool at Zero



Fig. 18 Tool at +0.006 In.



Fig. 19 Tool at +0.012 In.

FIGS. 17, 18, AND 19 SUCCESSIVE STEPS IN FORMATION OF A CHIP
(Free-cutting screw-stock brass, bar X; depth of cut, 0.010 in.; 15-deg. front-rake tool; actual magnification 85.)

resembles very closely that shown in Fig. 13. The actual depth of cut in Fig. 13 is slightly larger than that shown in Fig. 8, due to the digging in of the 45-deg. front-rake tool. The actual depth in Fig. 13 is 0.0107 in., whereas 0.010 in. was anticipated. The tool itself is rotated 2 deg., but this has been taken into account in determining the shearing angles above.

Free-Cutting Screw-Stock Brass. With a 16-mm. objective, a 7.5X-hyperplane eyepiece, the tube of the microscope set at 165, and the plate of the camera placed approximately 14 in. back of the eyepiece so as to give an actual magnification of 100, a free-cutting screw-stock brass, indicated as bar X, was photographed when being cut with the 15-deg. front-rake tool taking a depth of cut of 0.005 in. Three positions of the tool are shown in Figs. 14 to 16, inclusive. In Fig. 14 the tool is shown at the position indicated as zero. At this instant a section of the chip is shown about to be removed from the main portion of the material. The line of shear is a curve extending from the point of the tool to the left, concave upward, until it reaches the upper surface of the material. Watching carefully through the microscope, this line appears to represent a clean-cut surface, and the section of the chip appears to be entirely free from the main portion of the material. The chip, however, is continuous; that is, each section is attached to the next, so that it is not a definite plane of cleavage. A tool travel of several thousandths of an inch was still required before this chip section was completely formed and pushed off in a shape similar to those shown preceding it.

It was repeatedly observed that, with this 0.005 in. depth of cut, a new section was formed each time the tool was advanced to the left a distance of 0.012 in. When the depth of cut was



Fig. 21 Tool at +0.004 In.



Fig. 20 Tool at Zero



Fig. 22 Tool at +0.008 In.

FIGS. 20, 21, AND 22 SUCCESSIVE STEPS IN FORMATION OF A CHIP
(Non-leaded, 1/2-in. thick sheet brass, bar 26; depth of cut, 0.010 in.; 15-deg. front-rake tool; actual magnification 81.)

0.010 in., a section was formed every 0.018 in. of tool travel. These sections for the free-cutting brass were very regular and equal in size. Fig. 15 shows the position of the tool after it has traveled a distance of 0.024 in. from the position shown in Fig. 14. The various chip sections in Figs. 14, 15, and 16 are readily identified. In order to prevent the material of the chip from being pressed over the edge of the tool, the vertical face of the tool is nearer the objective of the microscope than the vertical face of the material being cut. This causes a shadow to be shown below the bottom of the tool from the light above. The white line indicates the tool edge.

Figs. 17 to 19, inclusive, show the free-cutting brass being cut with a 15-deg. front-rake tool, with a depth of cut of 0.010 in.,

but an actual magnification of 85. The cutting conditions are very similar to those having 0.005 in. depth of cut. In both cases the various sections of chip consist of material completely shattered, due to the pressure built up on the tool point. In other words, each chip section consists of a large number of laminated strips or elements which are too numerous to count.



Fig. 23 Tool at +0.012 In.



Fig. 24 Tool at +0.018 In.



Fig. 25 Tool at +0.024 In.

FIGS. 23, 24, AND 25 SUCCESSIVE STEPS IN FORMATION OF A CHIP
(Non-leaded, 1/2-in. thick sheet brass, bar 26; depth of cut, 0.010 in.; 15-deg. front-rake tool; actual magnification 81.)

Fig. 17 shows the position of the tool at zero; that is, a chip section has just been sheared off, and the new section is starting to be formed on the tool point. In Fig. 15 the tool has advanced 0.006 in. to the left and is gathering up the chip section on the face. Fig. 19 shows the tool advanced an additional 0.006 in., in which position the chip section is two-thirds completed, so that an additional 0.006-in. travel of the tool is required before this section is completed.

Non-Leaded Brass. Figs. 20 to 25, inclusive, show six positions of a 15-deg. front-rake tool when taking a cut 0.010 in. deep in the 1/2-in. thick non-leaded sheet brass, bar 26. Fig. 20 shows the tool at a position which is called zero. Each following figure shows the tool advanced an additional 0.004 in. The formation of each chip section of non-leaded brass appears to be very similar to that for the leaded brass. It was observed, however, that the various chip sections were not uniform in shape or size, nor were they as distinctly identified as in the case of the leaded brass. While there were definite shear lines visible, one section seemed to be pressed quite firmly into the next section. In these illustrations, Figs. 20 to 25, inclusive, the face of the tool being photographed projected slightly nearer the objective than the face of the material, in order to prevent the flow of the material over the edge of the tool and thereby obstruct its view. For this reason there is a slight shadow at the bottom of the tool. Due to the pressure of the chip on the tool face, the chip material was forced toward the objective and appears as light spots in the illustrations. Through the microscope the deformed area shown dark immediately ahead of the tool point is seen to consist of almost an infinite number of laminations, so that the material seems to be very uniformly crushed and sheared. These lines of shear are definite lines when viewed through the microscope, but in the illustrations these lines are not sharply defined, but as a group appear as a dark area. They curve concave upward from the tool point to the surface, making an angle with the horizontal smaller than for free-cutting brass. The six illustrations show progressively how the chip is formed as the tool is moved to the

left in six equal steps of 0.004 in., making a total of 0.024 in. travel. There appears to be no uniformity in these chip sections, and the chip as a whole appears more continuous than is the case with the leaded brass.

Cast Iron. Using the set-up as previously outlined to give a magnification of 81, a depth of cut of 0.010 in. on a cast-iron bar (No. 11–1) was first studied, but it was thought that the observations lacked definiteness, so that a depth of 0.020 in. was resorted to. There appeared to be no relation between the travel of the tool and the formation of any type of chip section; so five pictures have been taken, between each of which the tool has traveled 0.005 in., except that 0.010 in. travel was taken between Figs. 27 and 28. All of these pictures indicate that the bulk of the chip of cast iron is removed by virtue of a pressure built up on the face of the tool somewhat back of the cutting edge at a distance not greater than the depth of cut. The cutting edge itself seemed to do little work and that was in scraping over the surface from which the chip had been removed.

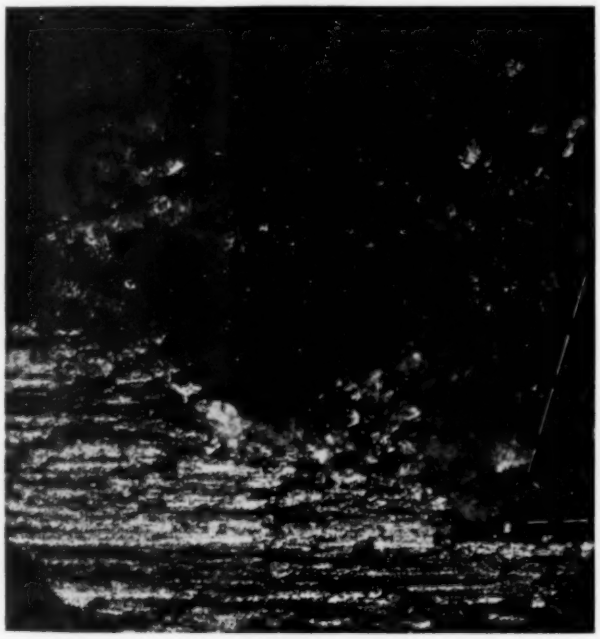


Fig. 26 Tool at Zero

Also, instead of removing the chip in large sections with little distortion, it appeared in most of these pictures that the cast iron was completely broken up into fine particles of no particular shape or size. No shear lines were observed. The cast-iron dust was blown away each time before the pictures were taken. Fig. 30 shows one illustration after the tool has advanced 0.005 in. from the position shown in Fig. 29, in which a large piece of cast iron is being removed as a solid body. The crevice to the left of the tool point extending horizontally is apparently the only fracture in this case. It may be that this particular formation of chip is due to a defect or an unusual condition of the material along the surface which failed. It has been observed that long chips of cast iron may be formed; the slightest touch, however, will cause it to crumble.

Free-Cutting Steel Screw-Stock. Figs. 31 to 36, inclusive, show six positions of the 15-deg. front-rake tool when cutting a free-cutting steel screw stock, bar 414, when taking a depth of cut of 0.010 in. The actual magnification is 81. In this case pictures were taken at each 0.005-in. travel of the tool. Fig. 31 shows the tool at zero—that is, at a starting point which was arbitrarily selected as the tool was in the process of cutting. The tool point is at the lower right hand of the lowest shear line and is just visible in the illustration. The shear line extends from the tool point in almost a straight line to the surface



Fig. 27 Tool at +0.005 In.



Fig. 28 Tool at +0.015 In.

FIGS. 26, 27, AND 28 SUCCESSIVE STEPS IN FORMATION OF A CHIP (Cast iron bar 11–1; depth of cut, 0.020 in.; 15-deg. front-rake tool; actual magnification 81.)

making an angle of about 13 deg. These lines of shear appeared to be outstanding at the start, but due to the pressure of the chip on the face of the tool and the resultant pressure on the material

being cut, the chip was compressed as it moved along the tool face, which caused these lines to become small, and in most instances practically losing their identity. In Fig. 31 one of these shear lines is shown at the start. In Fig. 32, after the tool has traveled 0.005 in., the shear line is still to be seen, but the material below the shear line to the left is being compressed and sheared into small laminations. In Fig. 33 the shear line is still clearly seen, but has traveled slightly along the tool face, and the material below is shown distorted. In Figs. 34, 35, and 36 the formation of the chip below this line of shear is shown. in which there are no major lines, but the metal itself shears and bends as it is being compressed on the tool point and forced against the portion of the chip above. The material ahead of the tool point is being distorted, making approximately a straight line at an angle of 20 deg. with a horizontal in Fig. 34, 24 deg. in Fig. 35, and 25 deg. in Fig. 36. This angle seems to vary at

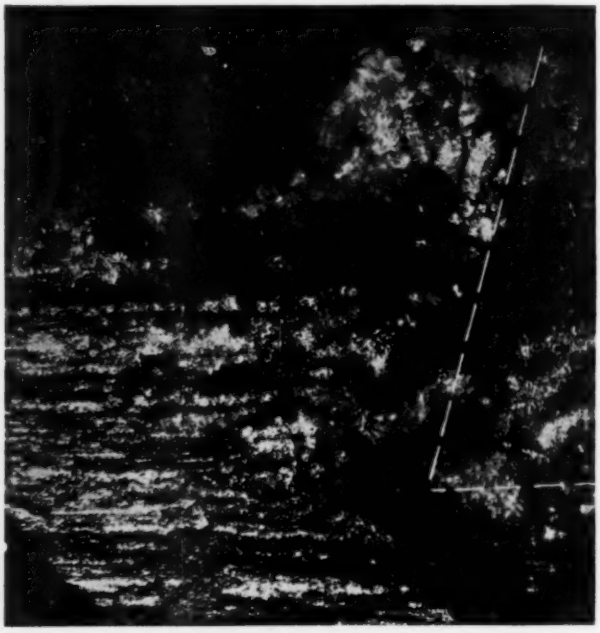


Fig. 29 Tool at +0.020 In.



Fig. 30 Tool at +0.025 In.

FIGS. 29 AND 30 SUCCESSIVE STEPS IN FORMATION OF A CHIP
(Cast-iron bar 11–1; depth of cut, 0.020 in.; 15-deg. front-rake tool; actual magnification 81.)

different positions. It was observed for this material that while the chip was being formed it did not bulge toward the objective of the microscope as much as low-carbon steel.

After making many observations through the microscope during the formation of this material into chips in a dry condition, lard oil was applied from a lubricating can to the point of the tool and adjacent work. It was noticed that the chip was formed with less distortion. The chip seemed to be smaller and more dense. No sharply defined lines of shear between sections of the chip could be observed as when cutting dry, as shown in Fig. 33.

Low-Carbon Steel. It was difficult to get clear observations when cutting the low-carbon steel because of its tendency to bulge when being compressed by the tool. This bulging caused the material being deformed to move out of the plane of focus. In making such observations, the microscope was focused at different times on the tool, on the chip, on the material before being cut, and on the material at the point of rupture ahead of the tool. This last point seemed to be most interesting, so that most of the photographs were taken with this point in focus. In Fig. 37 is shown a chip 0.005 in. in depth being cut by a 15-deg. front-rake tool. The magnification is 100. The vertical lines on the original surface of the material were cut 0.010 in. apart on a dividing engine so as to make it possible to compare directly the various distances in the illustration. It is seen that the material is sheared or pushed to the left from the tool point seen in the lower right-hand corner, on a curved line starting at an angle of approximately 0 deg. and ending at 40 deg. above the horizontal. The point at which this shearing surface intersects the upper surface is at the point where the chip begins to bend. The top surface is pushed to the left by the previous cut. The actual length of the line of shear from the tool point to the top surface of the metal is about 0.015 in., or about 2.5 times the depth of the cut.

Figs. 38(*a*) and 38(*b*) show a chip being removed by a 30-deg. front-rake tool. In Fig. 38(*a*) the magnification is 65.5, and the depth of cut is 0.005 in. The line of shear from the tool point to the surface of the chip appears to be a straight line making an angle of about 37 deg. above the horizontal. The material is distorted when about 0.010 in. ahead of the tool point as against 0.015 in. in the case of the 15-deg. front-rake tool. In Fig. 38(*b*) the same 30-deg. front-rake tool is used, but the depth of cut is 0.015 in., and the magnification is 87. The line of shear ahead of the tool point, between the solid material and the chip being formed, is about 10 deg. It appears, then, that with an increased depth of cut, the material ahead of the tool is distorted in greater proportion. In Fig. 38(*a*) there appears to be a definite tear line in front of the tool point. In most of the observations through the microscope, this tear was not visible, so that the tear indicated may be but the result of shadows in the illustration. The vertical lines scratched on the material below the tool are spaced 0.010 in. apart and are visible in Fig. 38(*b*) on the surface of the chip where they are compressed to practically half that distance apart.

Figs. 39, 40, and 41 show the same low-carbon steel being cut with a 45-deg. front-rake tool when the depth of cut is 0.010 in. Fig. 39 shows the tool at the starting point called zero, which is an arbitrary point selected after the tool had cut some distance. Fig. 40 shows the tool after it is advanced 0.010 in., and Fig. 41 after it has advanced an additional 0.005 in., or a total of 0.015 in. from that position shown in Fig. 39. Various points on the chip and surface of the material may be identified in the three illustrations. The tool point is seen in the lower right-hand corner. The lines of shear, or those lines on the surface of the material indicating failure due to the pressure on the tool, are readily seen in the three illustrations at an average of from 25 to 30 deg. from the horizontal. They vary with the position of the tool, other conditions being equal. With this high rake angle, the chip seems to be removed with less distortion and with less increased thickness than with smaller front-rake angles.



Fig. 31 Tool at Zero

Fig. 42 shows a 60-deg. front-rake tool taking a depth of cut of 0.005 in., when magnified 87 times. A 0.010 in. depth of cut caused the tool cutting edge to fail by breaking off so that the lighter cut was used. As in the case of the 45-deg. tool, the ratio of the depth of cut to chip thickness has increased but little.

It appeared that the cutting edge of the tool was rather blunt. This may be due to the high magnification or to a poorly ground tool, or it may be due to the material built up on the cutting edge, or even material covering the cutting edge in the field of vision.

The formation of the chip, however, seemed to be similar for all values of rake angle. The lines of shear were about 60 deg. from the vertical. There is more rubbing on the tool face for lower rake angles. Fig. 42 shows practically no contact between the face of the tool and the chip other than at the point of the tool.

In general, looking through the microscope as the tool is advanced slowly into the work, the lines of shear extending from the tool point to the surface of the work at an average angle of 30 deg. from the horizontal are rotated as the chip passes the tool point, due to the pressure of the material being formed into a chip at the tool point. Also, as the chip slides along the face of the tool, the bottom surface of the chip in contact with the tool face is held back, presumably by friction,

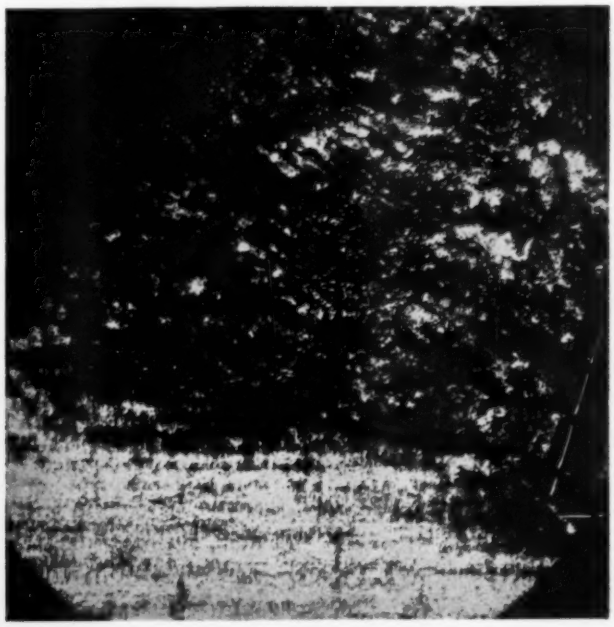


Fig. 32 Tool at +0.005 In.

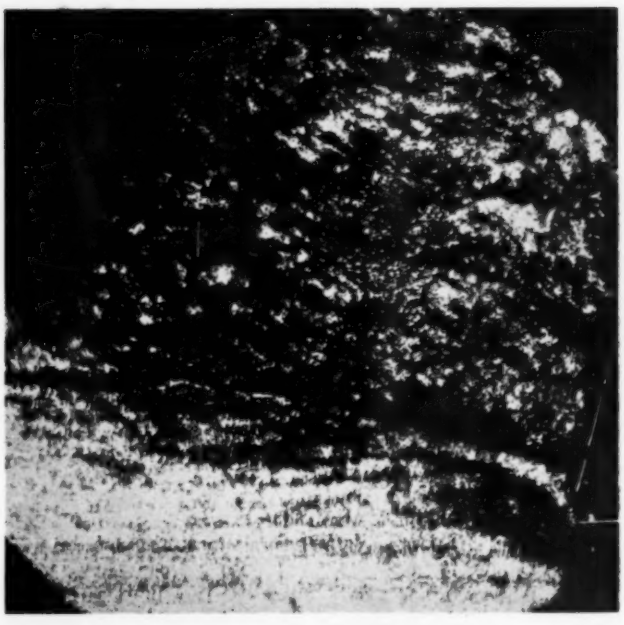


Fig. 33 Tool at +0.010 In.

FIGS. 31, 32, AND 33 SUCCESSIVE STEPS IN THE FORMATION OF A CHIP

(Free-cutting steel screw-stock bar 414; depth of cut, 0.010 in.; 15-deg. front-rake tool; actual magnification 81.)

which may account for the rough torn surface on the bottom of the chip. This condition is shown clearly in Figs. 31 to 36, in which free-cutting steel screw stock is cut, while the opposite is true when cutting cast aluminum, as shown in Figs. 8 to 13, inclusive.

Influence of Cutting on Crystalline Structure of Low-Carbon Steel

A photomicrographic study was made of a chip of the same 0.15 per cent open hearth, annealed carbon steel. A cut 0.020 in. deep with a 30-deg. front-rake tool was made for a length of approximately 2 in., when the cutting was stopped, the tool was withdrawn, and the section of the metal forming the chip about the tool point was cut out. This section was cast in Wood's (bismuth) metal, after which the surface was polished and etched. Fig. 43 shows this section when magnified 30 times. The structure of the chip as well as the uncut material about the tool point is seen. Fig. 44 shows an enlarged view (100 magnification) of the section about the tool point. A built-up nose is shown. The exact location of the tool point is not known, although it is believed to be dulled sufficiently to permit the portion of the built-up nose below *B* to ride on the cutting edge. The tool had previously been very carefully ground and lapped, however. Unfortunately, to the right of *B* an inclusion appears which to some extent handicaps the analysis. The small ribbon appearing on the under side of the chip is believed to be a built-up nose extending for some distance along the face of the tool above the cutting edge.



Fig. 34 Tool at +0.015 In.

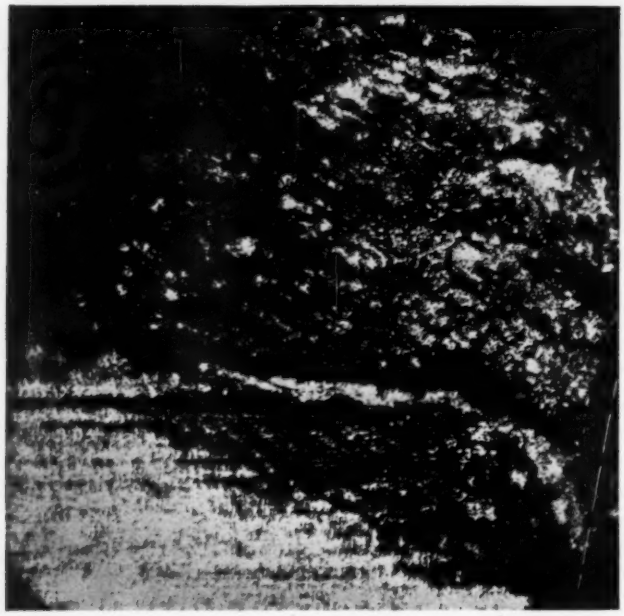


Fig. 35 Tool at +0.020 In.

After examining the specimen itself under the microscope at from 100 to 700 magnifications, the following conclusions were reached: That portion of the nose bearing on the horizontal surface just cut is integral with the main portion of the metal. No lines of cleavage were visible. The actual tip of this built-up nose is firmly embedded in the metal ahead of the tool point. From the actual tip of this nose a crack appears extending parallel to the face of the tool between the ribbon and the main portion of the chip. The ribbon appears to be completely separated from the chip, and the chip appears to be sliding over the upper surface of the ribbon. The ribbon itself, of which only two-thirds is visible in Fig. 44, the upper one-third projecting into space as seen in Fig. 43, appears to have a structure quite different from that of the main chip. The grain size is larger and does not give the appearance of having been compressed unless equally on all sides. It is not laminated parallel to the tool face.



Fig. 36 Tool at +0.025 In.

Figs. 34, 35, and 36 Successive Steps in the Formation of a Chip (Free-cutting steel screw-stock bar 414; depth of cut, 0.010 in.; 15-deg. front-rake tool; actual magnification 81.)

It appears in Fig. 44 that there is a definite connection between the ribbon and the main portion of the chip at *B*, which is that section containing the inclusion. A careful examination, however, at higher magnifications shows this to be not the case, but rather the ribbon is quite independent of the chip from a point adjacent to the built-up edge.

The chip itself appears to be sheared into elements extending from the point of the built-up nose along a straight line upward and to the right, making an angle of 42 deg. with the horizontal. As the tool advances, this metal being formed into a chip slides over the built-up ribbon, causing the under surface of the chip to be retarded on account of friction. These original straight lines of shear at 42 deg. with the horizontal, therefore, are gradually distorted so that their lower ends are turned toward the tool point and become almost parallel with the tool face at the point of contact with the ribbon. This same condition is shown by Herbert (Ref. 26) and others. It is curious, however, that an examination of the under side of many continuous chips produced in this way, instead of showing the ends of these various elements pointing toward the tool point (that is, toward the original metal), shows file teeth or edges pointing away from the tool point. It is true, however, that the file teeth formed on the under side of the chip point away from the tool

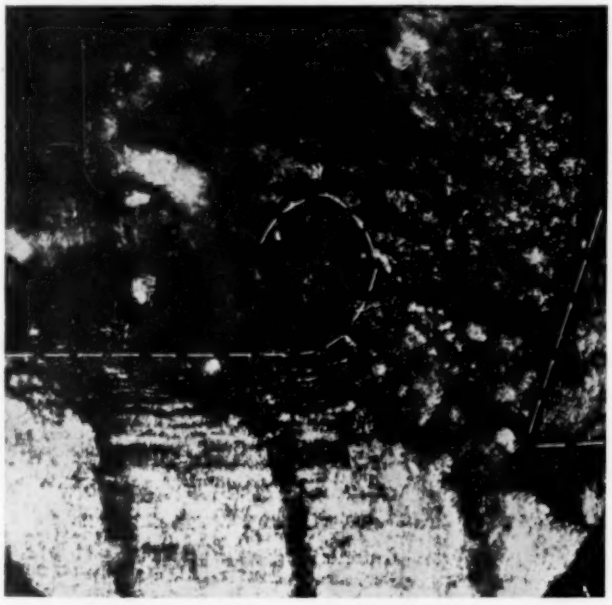


FIG. 37 LOW-CARBON STEEL
(15-deg. rake tool; 0.005 in. depth of cut; actual magnification 100.)

point, but the chip elements themselves are bent under so as to point toward the tool point.

Another point of interest is to note the amount of distortion below the newly cut surface. The various crystals have been dragged to the right by the built-up nose. At the same time they have been compressed. It is seen that the crystals are elongated—that is, flattened and turned parallel to the newly cut surface to a depth below the newly cut surface of approximately 0.006 in. It is also seen that the material immediately ahead (that is, to the right of the built-up nose in Fig. 44) is compressed clear to the edge of the picture, which is approximately 0.017 in.

Fig. 45 shows a view at 100 magnifications of the outer surface, shown in Fig. 43, of this low carbon steel chip. The letters *A* and *C*, in Fig. 45, may be readily identified with similar letters in Fig. 43. While the shear lines from the point of the built-up nose intersect the upper surface of the metal at a point *A*, it is believed that distortion occurs as far to the right as point *C*. The distance from *A* to *C* is approximately 0.020 in. It might be argued that the distortion below *C* is due to the previous cut. This may be so, but several previous very shallow cuts were taken purposely to avoid this difficulty.

A BRIEF REVIEW OF SIMILAR WORK OF OTHER EXPERIMENTERS

C. F. Roby (Ref. 11) has described his observations of successive steps in the formation of a milling-cutter chip. A



FIG. 38(*a*) LOW-CARBON STEEL
(30-deg. rake tool; 0.005 in. depth of cut; actual magnification 65.5.)

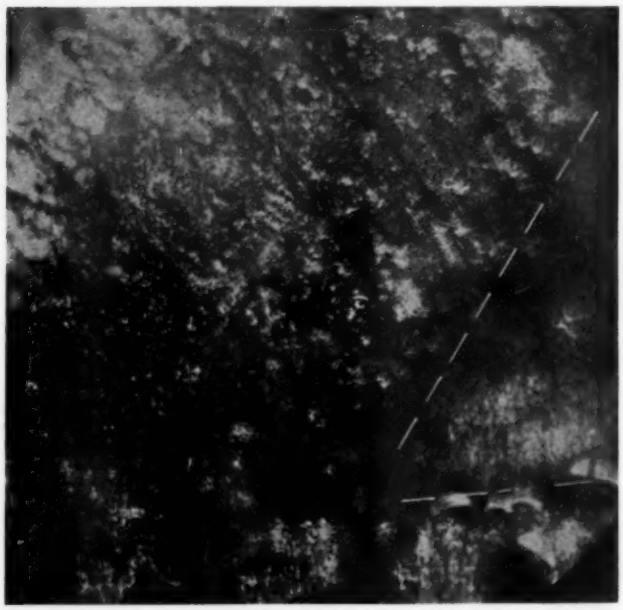


FIG. 38(*b*) LOW-CARBON STEEL
(30-deg. rake tool; 0.015 in. depth of cut; actual magnification 87.)

cutting speed of 1.5 ft. per min. was obtained. Paraffin and lead were first employed as test materials. The former crumbled under the pressure of the cutter, and the latter proved to be too soft for experimental purposes. Babbitt metal was found to be satisfactory, and a comparison of chips from this alloy and from the steel showed that the cutting action was the same in both cases. Tests were made with rake angles of the

milling-cutter tooth ranging from zero to 20 deg. Roby concluded that the tool compresses the metal until the load is sufficient to shear a chip off in sections. After this slip or shear of the section has taken place, the point of the tool slides over the surface and gives it a finish. This statement is contrary to those of Herbert, but substantiate many of the observations of the author.

Roby states further that while the metal is being compressed it is deformed and spreads out over the face of the tool. If a heavy cut is taken this lateral strain becomes great enough to split the chip before it shears off. A small rake angle on the tool has a tendency to cause the same condition. After one chip section is sheared off, another begins to form, and the preceding section slides over the tool and away from the work. This slip action is accompanied by a slight turning action, and the two combined cause the tool to wear away on the face just back of the cutting edge. The size of the chips depends upon the kind of metal cut, the depth of cut, and the cutting speed. In the case of a soft ductile metal such as steel, the section of chip which is sheared off does not drop away, but is held in place by properties inherent in the metal, and a succession of these chips curls off and forms a long shaving. Cast iron, how-

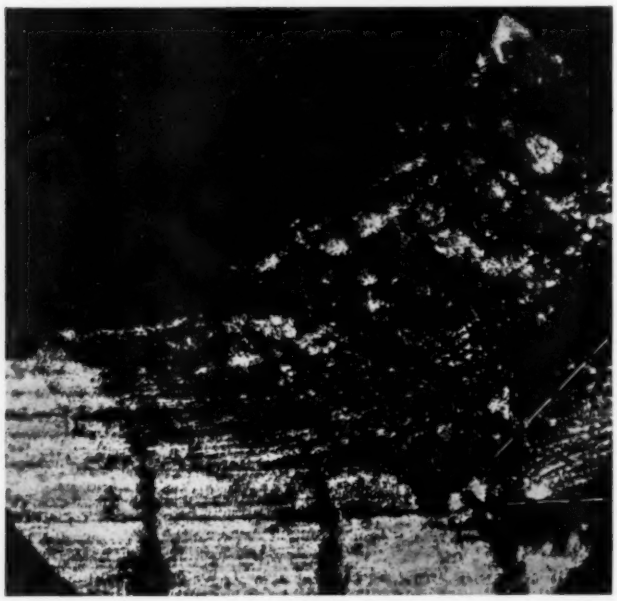


FIG. 39 LOW-CARBON STEEL
(45-deg. rake tool; 0.010 in. depth of cut; tool at zero; actual magnification 100.)

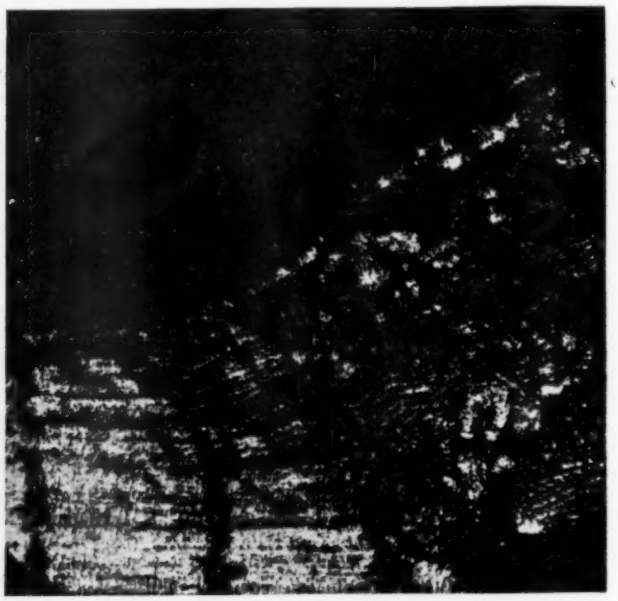


FIG. 41 LOW-CARBON STEEL
(45-deg. rake tool; 0.010 in. depth of cut; tool at +0.015 in.; actual magnification 100.)

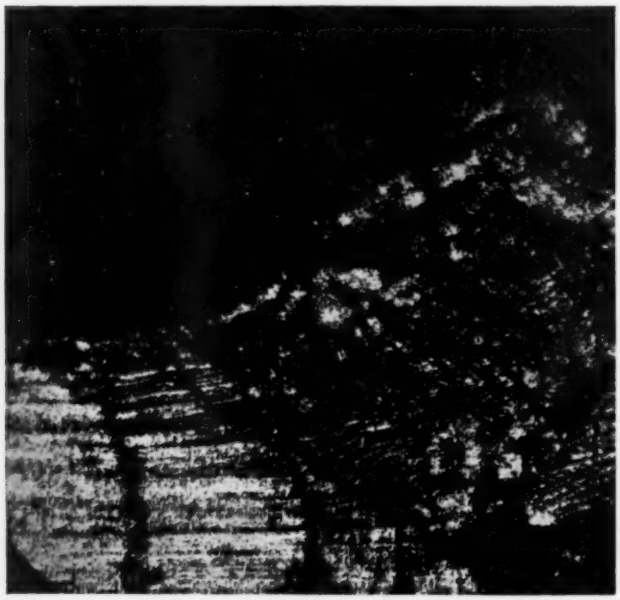


FIG. 40 LOW-CARBON STEEL
(45-deg. rake tool; 0.010 in. depth of cut; tool at +0.010 in.; actual magnification 100.)



FIG. 42 LOW-CARBON STEEL
(60-deg. rake tool; 0.005 in. depth of cut; actual magnification 87.)

ever, acts differently, the chips dropping away directly as they are sheared off. Roby states that there was no crack preceding the point of the tool—that is, no tear type of chips. This agrees substantially with the observations of the author. The angle at which shear takes place ranges between 24 and 31½ deg. with the horizontal, but varies with the material, the depth of cut, and the rake angle of the tool. The author found many of these angles to be as low as 10 deg. Roby states that this angle increases as the cut deepens and as the rake of the tool is increased. As the angle increases, the area of shear becomes less, and therefore the shearing stress becomes smaller. This may account for the fact that a thick chip is removed with less power than a thin one. He states further that this is probably true only up to the point at which the chip begins to split and crumble, after which power is wasted in deforming the chip. It is to be noted that all of the illustrations shown by Roby indicate that the chip as formed consists of very definite sections. These sections seem to be built up on a ribbon which furnishes the contact with the face of the tool.

William Rowell (Ref. 7) reports that the built-up edge forms almost instantly after cutting starts and that high-speed-steel tools are particularly prone to develop the built-up edge, which explains in a way why high-speed steel is not as satisfactory as carbon tool steel for finishing tools. Inasmuch as the tools used by the author were all high-carbon-steel tools, he is not able to comment on this feature. A few years ago, however, an attempt (Ref. 21) was made to note differences in forces required to cut a given metal under conditions which were constant, except that one tool was of carbon steel and the other of high-speed steel. No differences in forces could be detected.

Rosenhain and Sturney in their "Report on Flow and Rupture of Metals During Cutting" (Ref. 17) concluded that chips were of three different types—namely, tear, shear, and flow. They report that in the tear type of chip the chip is separated from the stock by means of a tear running well ahead of the tool point and "the whole of the chip moves outward relatively to the tool until rupture occurs; then the tool impinges upon fresh metal. This action is likely to result in considerable wear on the cutting edge." The author's Figs. 6, 11, and 30 indicate this tear type of chip. They report further that when the flow type of chip is formed, the metal leaves the stock in a ribbon which is more or less unbroken. The deformed zone or built-up edge is stationary so far as motion relative to the tool is concerned and acts as a protection to the nose of the tool. The actual cutting action proceeds from the apex of the deformed zone (see Figs. 7 and 47). So long as the chip continues to come off in a continuous ribbon or breaks from a point distant to its root, the only wear on the tool will occur on a point some distance from the nose. This wear will be greater with small top-rake angles (compare Figs. 7 and 13).

They report that the shear "type of chip is produced under conditions intermediate between those producing the tear type on the one hand and the flow type on the other; for example, a small depth of cut combined with a small top-rake angle." Figs. 2 to 5 and 14 to 17, inclusive, illustrate this type of chip.



FIG. 44 ENLARGED VIEW AT TOOL POINT OF FIG. 43
(Actual magnification 100.)

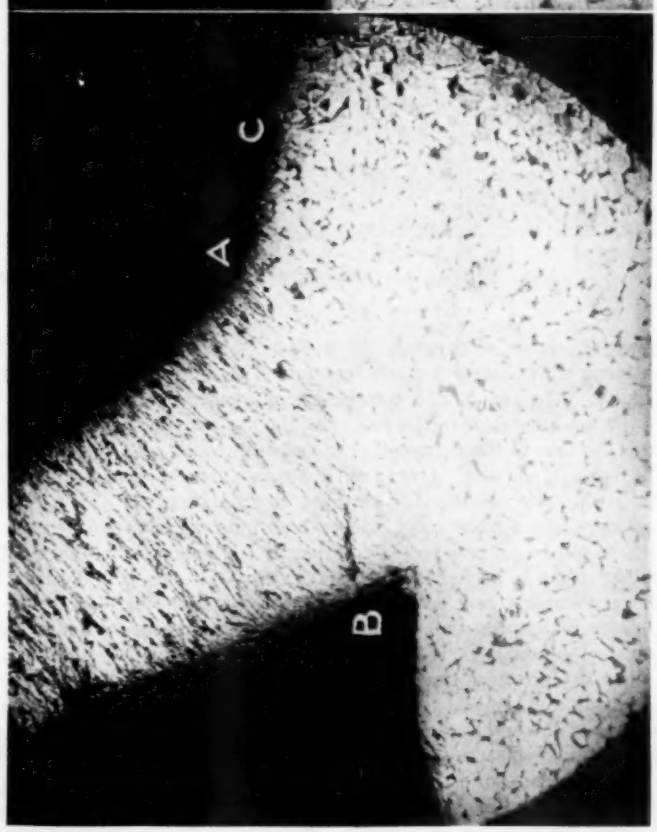


FIG. 43 POLISHED AND ETCHED SECTION OF A CHIP
(Cut by an end-cutting 30-deg. front-rake tool with no side rake; material is 0.15 per cent carbon oil-hardened and annealed steel; depth of cut, 0.02 in.; actual magnification 30.)

It is further reported that the built-up edge on the cutting tool, which has been the subject of so much discussion, appears by microscopic examination as not produced by particles scraped from the work which form themselves into a solid mass between the work, chip, and nose of the tool.

"The material in the zone is strongly deformed. The structure is sufficiently well defined to indicate that it certainly has not been deformed by the building up of any considerable number of separate particles. The continuity of the metal in this severely deformed zone with the metal of stock and chip can further be demonstrated by a simple experiment. Annealing causes the rapid recrystallization of deformed metal and the reestablishment of normal microstructure. It is well known, however, that such a new microstructure is never continuous; that is, the structural constituents do not cross the finest crack, nor even the line of a weld. The deformed zone in the present experiments, however, shows after annealing a microstructure perfectly continous with that of the adjacent metal, thus proving real continuity. The area of the deformed zone appears to be related to the top-rake angle of the tool. As the top-rake angle is increased, the area of the deformed zone decreases, until with a top-rake angle of 30 deg. it entirely disappears, for brass. If this deformed zone consisted of particles scraped from the work, its disappearance when using a tool whose top-rake angle was 30 deg. would be an unexpected coincidence. The conclusion therefore seems to be indicated that the deformed zone is produced by crumpling and deformation of the metal during the first stages of cutting, the amount of such crumpling depending on the top-rake angle of the tool."

The author has previously explained in reference to Fig. 44 that the built-up nose appears, at all magnifications up to 700 to be continuous on the bottom and along the front of the rectangular section immediately about the point with the adjoining metal. It also appears perfectly clear that the ribbon extending from the nose along the face of the tool underneath the chip is distinctly separated from the chip proper.

In watching the growth of the built-up edge of aluminum as illustrated in Fig. 7, it first appeared as a built-up edge similar to the one shown, but much smaller, and quickly grew in size to that shown which, for the tool shape and size of cut, appeared to be the normal, from which no further divergence occurred. Obviously, Rosenhain's statement as to the continuity of material between the chip and built-up nose agrees with those observations of the author immediately at the built-up nose point, but not beyond this point. The author cannot justify the so often-used term "weld" in connection with this built-up edge. Heat is unquestionably created as the metal is deformed, but many observations where the metal is not even colored show results similar to those when the metal is colored. If welding did occur, certainly the metal would show it. Rosenhain shows in his Fig. 16, for brass, that the chip is not the result of welding because "the built-up nose is continuous, and the structural constituents do not cross the finest crack, nor even the line of a weld."

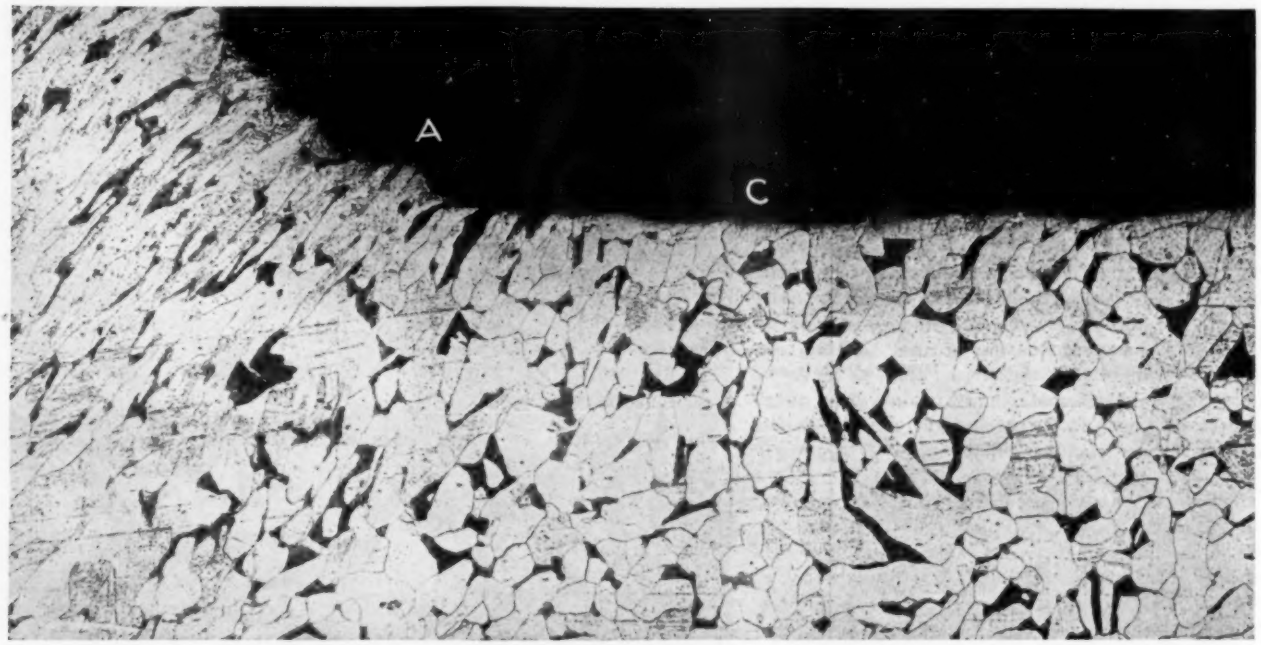


FIG. 45 ENLARGED VIEW OF OUTER SURFACE OF CHIP FORMED IN FIG. 43
(Actual magnification 100.)

Coker has shown (Ref. 14) that when cutting a mild-steel plate taking a shaving of 0.010 in. in thickness with a tool having a front-rake angle of 30 deg. and a clearance of 3 deg., the distorted area in front of the tool has a boundary, when cutting dry, extending from the point of the tool to the surface considerably ahead of the tool along a concave upward curve. When a trace of lubricant is introduced, this boundary line, or shearing plane, is considerably shortened and becomes practically a straight line. The author did not observe this particular condition, at least not in this exaggerated form. It was observed, however, that the chips were more compact and slightly less distorted.

Klopstock (Ref. 15) concludes that there is no doubt that the process in turning is the same as that in planing, notwithstanding the fact that chips from the two processes were taken at entirely different cutting speeds. The surfaces from which the chips were cut also show similar appearance. Klopstock photographed successive steps in the formation of chip elements

and concluded that the process of cutting might be divided into four parts: (1) the initial compressed material in front of the tool, causing the tool to get its first new grip on the work piece after a chip has been broken off; (2), a slight initial tear is caused between the main part of the work piece and the material which is to form the next chip element; (3) the material which is to form the next chip element is compressed and bulges on the lip surface; (4) a tear is caused between this material and the main work piece. This tear is generally not complete but, with the exception of cast iron and similar materials, a certain connection remains between the individual chip elements. He concludes that this conception explains the oscillating form of chip pressure curves obtained by Nicolson and others. In these curves the points of maximum pressure represent the moment of maximum compression of the chip elements, while the lowest points immediately succeeding the points of maximum represent the instants after the chip elements have been broken off.

Codron's conception of the formation of a chip is also reproduced, which agrees substantially with that of Klopstock. The author believes that these conceptions are substantially

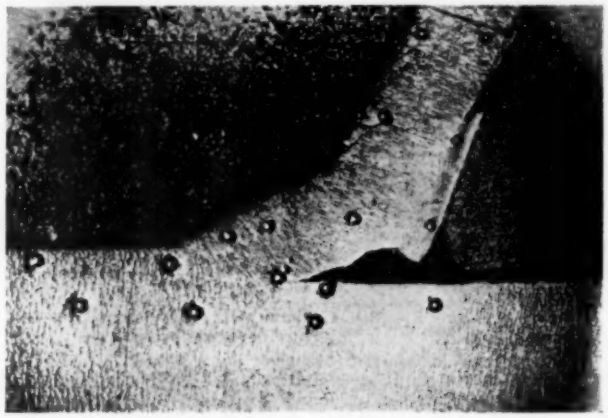


FIG. 46(a) FIRST STAGE IN FORMATION OF "BUILT-UP" EDGE IN STAINLESS IRON B
(After E. G. Herbert. Actual magnification 10.)

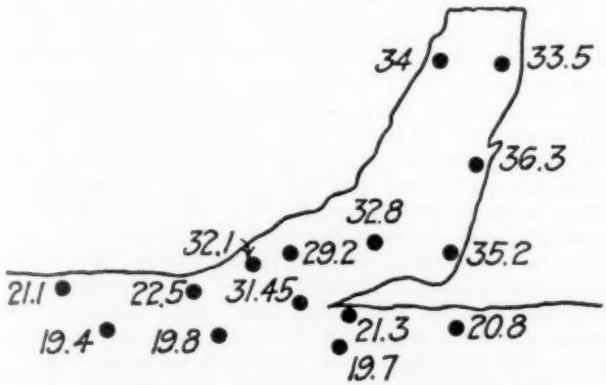


FIG. 46(b) DRAWING FROM FIG. 46(a)
(After E. G. Herbert.)

true, but that the shearing action referred to is more continuous than that appreciated by Klopstock or Nicolson; that is, that each individual chip element or section in itself consists of a large number of laminated sections. Klopstock further reports that the subdivision into chip elements is not always noticeable. Some chips may consist partly of clearly separated chip elements and partly of rather continuous sections, in which the individual chip elements can hardly be recognized. This agrees with the observations of the author.

Mr. E. G. Herbert has reported (Ref. 26) on a detailed study made of the cutting action of roughing tools having a top-rake angle of 20 deg. It was found that "the implement which actually does the cutting in such cases is not the tool, but the structure known as the "built-up edge," an intensely hard body roughly triangular in section formed by the welding of successive layers of material derived from the zone of the cut and deposited on the point of the tool so as to protect it from contact with the

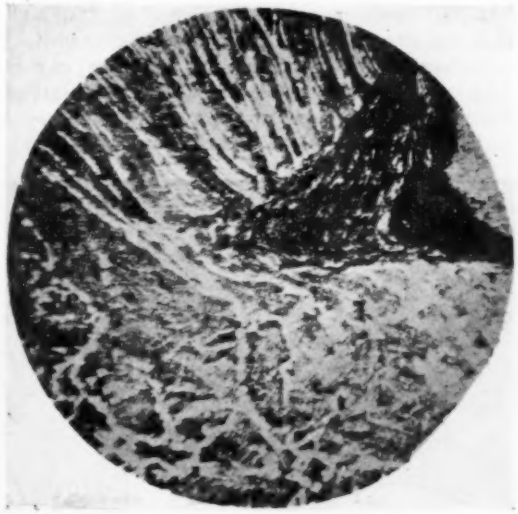


FIG. 47 "BUILT-UP" EDGE IN MILD STEEL
(After E. G. Herbert. Actual magnification 50.)

material it is ostensibly cutting. It is reported that the first stage in the formation of a built-up edge consists in dragging a layer of steel from the under side of the chip through the intense frictional resistance between the chip and the top surface of the tool over which it is constrained to flow. This thin layer separates itself from the chip and attaches itself to the tool, and a second layer, similarly formed, "welds itself onto the top of the first, this process being repeated until the complete edge is built up of innumerable layers welded together." The author has often found this to be the case, except that he does not like the word "weld." Fig. 44 shows an exceptional case.

Fig. 46(a) and Fig. 47 show, respectively, Herbert's conception of the first stage in the formation of the built-up edge and the built-up edge after the tool has cut continously. Unfortunately, Herbert's original paper (*Trans. A.S.M.E.*, 1926, Vol. 48) shows that Fig. 46 applies to stainless iron, B, whereas Fig. 47 applies to mild steel. There may, therefore, be some doubt as to this conclusion. Figs. 2 to 7, inclusive, for aluminum, in this paper, confirm this conclusion. Herbert reports that "owing to the steep slope of the top face of the tool, the built-up edge is not able to find a permanent resting place, but slips off the tool as soon as it has been formed. It is carried away by the chip, from which it has never become completely detached and can be seen as a series of ridges on the under side of the chip." It is reported that some of the temporary edges were formed and discarded not less than fifty times a second. It is reported, further, that the structure of the edge is continuous with that of the chip, as originally pointed out by Rosenhain and Sturney (Ref. 17).

Herbert further reports that the cutting speed has a great deal to do with chip formation. Photographs of cut and polished

sections through the cutting edge, taken at the lowest speed of 7.45 ft. per min., at a standard speed of 61 ft. per min., and at the highest lathe speed of somewhat less than 165 ft. per min., are given in Figs. 48, 49, and 50, respectively. These were taken in turning a mild steel bar (8X) with a feed of 55 turns per inch and a depth of 1/4 in., with a 35-deg. top-rake tool having a 7-deg. side clearance. This top rake was actually side rake on a side-cutting tool. The conclusions drawn from these speed tests were that, with the standard speed of 61 ft. per min., the amount of distortion, judged by the thickening of the chip, was less than at higher or lower speeds, while the average hardness of the chip was also less at this standard speed of 61 ft. per min. At the three lower available speeds (7.45, 12.2, and 18 ft. per min.), the chip formation was reported as abnormal. There was no built-up edge, and the chip was segmented in a manner not found in any other cuts (see Fig. 48). It was further concluded that a study of chip formation at very slow speeds can give no guidance as to what occurs under normal conditions; also, that a study of chip formation at the very commencement of cutting gives no indication of what occurs when cutting is continued long enough to become normal.



FIG. 48 EFFECT OF SPEED ON CHIP FORMATION IN MILD STEEL
(Speed of 7.45 ft. per min. After E. G. Herbert. Actual magnification 8.)

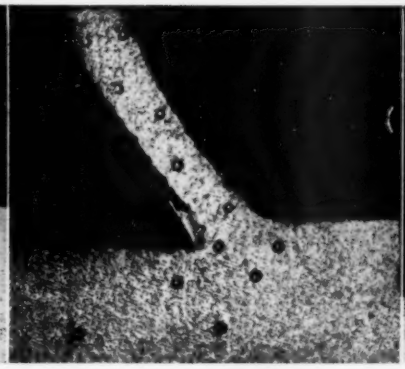


FIG. 49 EFFECT OF SPEED ON CHIP FORMATION IN MILD STEEL
(Speed of 61 ft. per min. After E. G. Herbert. Actual magnification 8.)

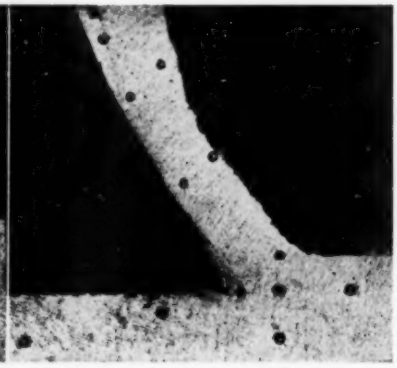


FIG. 50 EFFECT OF SPEED ON CHIP FORMATION IN MILD STEEL
(Speed of 165 ft. per min. After E. G. Herbert. Actual magnification 8.)

The speeds used in taking the cuts considered in this paper were all below the 18 ft. per min., considered by Herbert to be below the normal, and yet in several instances the conditions observed agree with Herbert's conclusions, as though higher speeds had been used. It seems, therefore, that possibly the conclusion of Herbert's as to the formation of chips at low speeds is not final. The present paper is considered as a first step in the investigation of "what happens when metal is cut." Photographs have been made of the tool only while stationary after taking a cut. It is hoped that this study may be continued into the second step of recording on a motion-picture film the continuous action of cutting on each of the materials at various speeds and from the starting of the cut until so-called normal conditions have been reached. Herbert's conclusions indicate that temperature must be an important factor in this so-called normal cutting—that is, cutting in which a built-up edge occurs. And yet, in this paper, the built-up edge was secured within 1/8-in. travel after the tool had started to cut at very low speeds. Many observations have been made in cutting at 20 ft. per min. on a planer, in which the beginning of 1/4 to 3/8 in. of the under side of the chip was burnished. From there on to the end of a 2- or 4-ft. length of cut, the under side of the chip was rough, presenting almost parallel cross-lines quite equally spaced. At the end of the cut the whole chip broke off and exposed a portion of metal which appeared to be the built-up edge. This held true for chips of 0.005 in. to 0.010 in. depth of cut. These cross-lines appear to be the pulled-out ends of the chip laminations. These ends appear as saw teeth or file teeth and actually point in a direction away from the tool point, while the bent under ends of the chip elements point toward the tool point. There seems to be no relation between the size of these file teeth and the chip elements, however. It does not seem from these teeth that the built-up edge is cast off frequently, as claimed by Herbert. There often is some evidence of the sloughing off of the built-up edge by the appearance of burnished spots or deposits at irregular intervals.

In the discussion of machinability Herbert reports that the measure of machinability is the hardness of the chip. The law of machinability takes into account not only all the characteristics of the metal, but also the machining process. Fig. 46(*b*) is a drawing of the photograph given in Fig. 46(*a*). The small dots are the places on which time-hardness values have been made with the 4-kg. Herbert pendulum hardness tester, equipped with a spherical-faced diamond of 0.5 mm. radius. The specimen was polished and etched after being cut from the original bar with a hand hacksaw. This represents the condition of the chip when the work was suddenly stopped during the process of continuous cutting. The specimen was mounted in pitch contained in a steel ring for polishing. It is seen that the hardness values of the uncut metal below the surface are smallest, averaging about 20. The hardness of the chip itself averages 50 per cent higher, while the hardness of the chip section in contact with the tool face averages 33 to 35. It is seen, therefore, that the hardness of the chip is greater than that of the uncut material, showing that it has been work-hardened. Herbert gives similar hardness tests results on chips of a wide variety of metals showing in every case that the hardness of the chip, which is the deformed material, is greater than that of the undeformed material. Manganese steel has a greater work-hardening capacity than most other steels, indicating one reason why it machines with difficulty. Brass and cast iron, on the other hand, have a very small work-hardening capacity, indicating their ease of machinability. The hardness of the chip depends on the capacity of the metal to become hard as a result of distortion and on the degree of distortion. Herbert explains that cast iron and brass are distorted very little. The author's observations, through the microscope, of continuous cutting do not bear this out. It was observed that leaded and non-leaded brass behaves, at the point of a cutting tool, as it is being formed into a chip, almost identically like steel; that the chip is made up of almost an infinite number of shear lines

or elements which may or may not be bound into segments shown in Figs. 14 to 25. Even Herbert's photomicrograph or a separate section of a brass chip shows that the structure of the chip itself is distinctly different from the original material, in that it has been sheared and compressed throughout.

Conclusions

It is not presumed that the study as outlined points the way to satisfactory and complete answers to De Leeuw's eleven questions listed at the beginning of the paper. The subject of "Chip Formation" and "What Happens When Metal Is Cut" has been considered and variously interpreted by many. It appears obvious that with variables such as materials, tool shapes, types of cutting, speeds, depths of cut, etc., complete correlation of the results of existing experimental observations is difficult. Many conflicting conclusions are reached regarding the various phases. Many conclusions are based on incomplete experiments or data. This study in the most part, for instance, is confined to deformation seen on the exterior of the metal. This study in itself is not final, but the first of two or three steps which, it is hoped, may make use of the X-ray and the moving picture. Final comprehensive conclusions can be drawn only after this information is complete.

Points which seem evident from the data presented as are follows:

1 It seems that the chips are divided into two types, those consisting of "sections" or groups of small laminations and those which are more or less "continuous," consisting entirely of uniform laminations.

2 Of those brass chips which are formed in sections, it appears that high lead (3 per cent), which is introduced into the metal as a free-cutting agent, causes laminations to be grouped into sections equal in size and of uniform shape at the beginning of the cut and at low speeds. For the low-leaded brass (1.44 per cent) under the same conditions, laminations were grouped into sections which were of unequal size and shape.

3 Comparing the chips of the high-leaded and low-leaded brasses when cut by a 15-deg. front-rake tool at 20 ft. per min., little difference appears. Both chips are "continuous," being made up uniformly of small elements and are not of the "section" type. The higher-leaded brass gives what appears to be a slightly more dense structure; that is, the individual laminations are smaller. Practically no difference exists in the horsepower required to remove a cubic inch per minute under similar conditions (*Trans. A.S.S.T.*, Vol. 16, No. 6, p. 659).

4 When high sulphur is used for free-cutting purposes such as in the screw-stock steel, it appears that the chip is more regular in its make-up as well as more dense in its structure. The individual laminations appear more distinct and regular than in the case of low-carbon steel.

5 In comparing chips of the screw-stock steel with those of the low-carbon steel when cutting with a 15-deg. front-rake tool at 20 ft. per min., the screw-stock-steel chips are seen to be more regular in their appearance and more continuous than those of low-carbon steel. The low-carbon-steel chip is badly deformed, very irregular, but obviously of the "flow" type—made up of laminated elements rather than grouped elements or "sections."

6 The chip of cast iron when removed at 20 ft. per min. appears also to consist of irregular laminations which easily become broken. The chip is very porous, and the laminations are held to one another apparently by mechanical contact only. The cast-iron chips appear to be very similar to, but less regular than, similar chips from cast Dow metal or cast manganese brass. The chips of both the latter when being cut at 20 ft. per min. by a 15-deg. front-rake tool are made up of loosely attached small laminations.

7 The size of the chips—that is, the ratio of the thickness of the chip to the original depth of cut—depends upon the kind of material cut, the tool shape or rake, the depth or cut, the speed of cutting, and whether cut wet or dry.

8 There appears to be some question as to the amount of metal in shear—that is, the slope of the lines of shear from the tool point to the surface of the metal as the front-rake angle of the tool is changed. It is definitely established that as the front-rake angle is increased, the cutting force expressed in pounds per square inch of original chip area is reduced in direct proportion for all metals (Ref. 21). This straight-line function, however, holds for some metals longer than others. For cast iron, when a front-rake angle of 25 to 30 deg. is reached, there appears to be no further reduction in force with increased rake angles. For carbon steel and most of the alloy steels, the straight-line function extends up to the 45-deg. front-rake angle. A satisfactory correlation between this straight-line function of reduced force with increased rake does not appear to be satisfactory when Figs. 37 to 42, inclusive, are considered, in which the low-carbon steel is cut with tools having front-rake angles of 15, 30, 45, and 60 deg., respectively. The angle of shear ahead of the tool point appears to be more nearly horizontal the smaller the front-rake angle. Figs. 38(*a*) and 42, in which the 30-deg. front-rake tool and the 60-deg. front-rake tool are cutting at a depth of 0.005 in., do not appear to bear this out, however.

9 It appears that when the tool starts to cut, the first few chips are of the "section" type (called "shear" type by Rosenhain). The material immediately ahead of the tool point bearing on the face of the tool seems to be crushed and pushed against the face of the tool by a resultant force which causes it to remain stationary in that position. This material then becomes the built-up edge which is forced into the material as the tool advances and seems to be the actual medium for separating the chip from the balance of the metal.

10 After the built-up edge is formed, the chips apparently become of the ribbon type (called "flow" type by Rosenhain), Many chips cut at high-speed are, however, of the "section" type.

11 Many photomicrographs by other experimenters show this built-up nose to consist of laminations. It is believed that these laminations are not the result of welding, but simply the result of compression under high pressure. Whether they actually consist of individual layers or simply material so distorted that it appears as layers seems uncertain. Rosenhain claims that the metal of the built-up edge, for brass, is continuous in itself and with the metal being cut. Herbert, on the other hand, claims that they are individual laminations gradually accumulated from the chip. It appears that this built-up edge is not material scraped from the cut surface by the tool edge, but rather material immediately ahead of the tool point which is crushed and pressed onto the tool face. It also appears that the cutting edge of the tool itself with depths of cut as low as 0.005 in. does not cut the surface or even drag over the surface left, but rather that the material ahead of the tool point is the only medium coming in direct contact with the cut surface left. Regardless of how fine the finish on a part, it does not appear as a burnished or clean-cut surface, but rather as a series of hills and valleys of the file-tooth type resulting from tear. For a good finish, these saw teeth become so small that they are not well observed by the eye.

12 It has been established that the force in pounds per square inch of original chip area required to remove the chip under given conditions becomes less as the original thickness of chip is increased (Ref. 21). Observations in this paper do not appear to be sufficient to make a correlation and complete

explanation possible. The material well ahead of the tool point is deformed even in addition to the so-called shearing of the metal into small laminations, and it is compressed and dragged below the cutting edge to a considerable proportion of the depth of cut. In addition, the chip is bent and compressed and forced over the face of the tool. Tearing in itself appears in most observations to be a small factor involved.

13 In cutting cast iron it is obvious that the cutting edge of the tool does a great portion of the work. After compressing the material ahead of the tool face and thereby forcing it over its face, the cutting edge proper scrapes along the finished surface, removing such irregularities as are left. These irregularities are then carried away with the balance of the chips.

14 When a lubricant is applied to the tool point, the steel chip appears to become more dense and more uniform in structure.

Acknowledgments

Grateful acknowledgment is made of the financial assistance secured for carrying on this project from the Department of Engineering Research of the University of Michigan. Prof. Claire Upthegrove of the Department of Chemical Engineering supervised the preparation of the photomicrographs shown in Figs. 43 to 45, inclusive, and also the analysis of these pictures. Mr. A. F. Parker, and Mr. H. A. Barnes did most of the preparing and setting-up of apparatus. All photographs were taken by them. The former proved very helpful in the preparation of the discussion.

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Discussion

During the discussion of the paper the following questions were asked:

A. Slovak. Is not lack of homogeneity the reason for the varying shearing angles?

E. O. Waters. Is there any theory to account for the consolidation or grouping of the primary shear elements into definite and approximately equal sections?

K. W. Legg. What effect has the condition of the face of the cutting tool on the chip? Is it better that the tool be lapped or have ordinary ground surfaces?

R. V. Hutchinson. Can one push the ribbon off with a scraper, or do you have to regrind the tool to remove the chip or built-up edge? Have you made any determination of the cutting pressure normal to the surface of the main body of the work, with variations of rake from which some information could be had as to what goes on inside the chip?

H. L. Blood. Have you found that the cutting speed has a great effect upon the sticking of metal to the point of the tool?

George Bouvier. If the polish on the tool or the cutting lubricant used affects the type of chip formation, does not that indicate that there is no deposit of welded material?

Author's Closure

It appears that homogeneity in itself is not the reason for the varying shear angles. No metal is strictly homogeneous and yet its cutting action appears to be consistently alike at various points. Certainly, wide variations in uniformity of the metal will cause the formation of the chip at various points to be somewhat different. The chemical analysis and structure are thought to have greater influence on the formation of the chip and the shearing angles than lack of homogeneity itself.

The author knows of no theory to account for the consolidation of primary shear elements into definite and approximately equal sections. It appears that when this condition occurs some free-cutting agent such as lead or sulphur which has been introduced into the metal is the cause. Not enough information is available for the author to draw such definite conclusions, and certainly experimenters in general do not agree sufficiently well on this point to make such conclusions obvious.

Messrs. Legg and Bouvier have raised the question as to the influence on the formation of a chip of the condition of the face of the cutting tool. The tools used in these tests were very carefully ground and then lapped, so that they presented a somewhat smooth and polished surface and keen cutting edge. If this honed or lapped surface did exert any influence it seems that it would be in preventing the formation of a built-up edge on the tool or would assist in causing this built-up edge to slide off more frequently with the chip. This did not seem to be the case. It appears from practice that the value of lapping or honing the face of a cutting tool is questionable. In some

instances increased tool life has been observed, but in other cases no appreciable increase in tool life seemed to result. Undoubtedly, with extremely fine cutting of 0.001, 0.002, or 0.003 in., the keenness of the cutting edge resulting from honing or lapping becomes more apparent. The present paper, however, does not definitely answer this question. There may be less frictional resistance as the chip slides over the face of the tool after it has passed the built-up nose. The introduction of a cutting lubricant would probably accomplish the same thing as lapping. It does not seem to prevent the formation of the built-up nose, but does seem to give a finer and more uniformly broken-up structure of the chip. It does not seem safe to say that it prevents the building up of the built-up edge. It undoubtedly does prevent the welding of the material in the built-up nose even if welding occurs when cutting dry. Inasmuch as the built-up edge is formed both in dry and wet cutting, it would indicate then, that welding is not the process underlying the formation of the built-up nose.

Mr. Hutchinson's question is not altogether clear. When the built-up nose is retained on the tool face after the completion of a cut, it can be pushed off with a scraper or it may be ground off.

It is not a welded contact. Often by starting the tool with the built-up nose on its edge in a new cut, the first built-up nose is simply pushed off and a new one formed. The author has not made any determination of pressures cutting normally to the face of the main body of the work. All of his measurements have been parallel to the direction of cutting. These results for various rake angles may be seen in Trans. A.S.M.E., 1926, Vol. 48, p. 749.

In answering Mr. Blood's question as to the influence of speed upon the sticking of the metal to the point of the tool, it may be seen from the results given that the built-up nose was formed even though the cutting speeds were very, very low, so the author believes that the built-up edge is formed regardless of the speed of cutting.

MSP-52-12

Some Practical Deductions From the Theory of Lubrication of Short Cylindrical Bearings

By F. E. CARDULLO,[1] CINCINNATI, OHIO

In this paper the author tells of desirable characteristics which a fluid lubricant should have, and explains the effects of viscosity. He develops a theory with many mathematical equations on the phenomena of longitudinal flow of lubricants in bearings. Conclusions are given regarding general design and operation of bearings, the load carrying capacity, the power loss, and the ultimate rise in temperature of a bearing operating continuously with a particular eccentricity ratio.

A LUBRICANT is a substance interposed between two rubbing surfaces for the purpose of reducing friction or wear. Fluid lubricants must have the following characteristics: (1) They must have suitable viscosity at the temperature at which the bearing operates, (2) they must have the ability to wet the metals which form the rubbing surfaces and adhere to the rubbing surfaces under the conditions of service, (3) they must not attack the journal or the box chemically, and (4) they must not be acted upon by air or other substances with which they come in contact in such a manner as to change their lubricating qualities.

A suitable viscosity is always regarded as a primary requisite of a fluid lubricant, but a few oils, and many other liquids which have a suitable viscosity, are lacking in the other characteristics which are necessary. For instance, mercury has a suitable viscosity, and is also a good conductor of heat, which would be a valuable property in a lubricant, but it will not wet a steel or iron surface, and will attack most bronzes. Linseed oil and other drying oils are not satisfactory as lubricants because they absorb oxygen and become thick and gummy when exposed to the air.

If a drop of any liquid be placed upon a clean horizontal surface it will either form a spherical drop, the particles of the liquid clinging together so as to expose the minimum surface, or else it will spread into a thin film which wets the solid surface and spreads indefinitely. A fluid which gathers in drops is said to have a high surface tension while one which spreads and wets the surface is said to have a low surface tension.

Unless a solid is completely immersed in a liquid, a second fluid is always present. The surface tension of a liquid depends upon the nature of the second fluid present, as well as of the solid surface with which it is in contact. Ordinarily the second fluid is air. It may, however, be some other gas, or a vapor or liquid. In a steam-engine cylinder, iron, oil, steam, and water are all in contact. At the high temperatures encountered in such service, a pure mineral cylinder oil will not wet the iron, since its surface tension is greater than that of very hot water in the presence of steam. The hot water therefore wets the iron, while the cylinder oil gathers in drops and becomes ineffective as a lubricant. The addition of a small percentage of tallow to the mineral oil will lower its surface tension below that of the water, so that the "blended" oil, as it is called, will wet the iron of the cylinder under the conditions of service.

It has been found that the addition of small quantities of free fatty acids to a mineral lubricating oil lowers its surface tension in the presence of metal, or in other words improves its ability to spread on a metallic surface and to wet it. Under certain conditions particularly in the presence of moisture, free acids in a lubricant will attack the bronze or the steel, roughening the surface and injuring the bearing. We are therefore limited to the use of those organic acids which are least active in attacking metals, and they must be used in such minute quantities as to have no objectionable effects.

Certain types of oils such as the drying oils already mentioned which by the absorption of oxygen from the air, or by other chemical change, gum or thicken, or oils which evaporate, carbonize, or become corrosive, rancid, or thin when exposed to moderate heat, to humidity, or to air, cannot be used for lubricants, although they have many of the properties necessary in a lubricant. This class includes all drying oils, mineral oils containing certain sulphur compounds, and all oils which are adversely affected by heat.

Of the four properties mentioned as necessary to a fluid lubricant, the one most readily susceptible of measurement is viscosity, and this property has received the most attention from investigators. Viscosity is sometimes called "body" or "thickness," and oil of high viscosity is said to be "heavy" even if it is of low specific gravity, and similarly a "light" oil is one of low viscosity even though it may sometimes have a dark color and a high specific gravity. In general high viscosity or "heavy" commercial oils used as lubricants have a dark color and a high gravity, while "light" oils or oils of low viscosity are usually also light in color and of low specific gravity. This is not, however, invariably the case.

Viscosity may be defined as resistance to flow. Experimental investigation shows that this resistance is in the nature of a resistance to a shearing movement and is proportional to the rate of shearing. It is different in its nature from the resistance to flow due to eddying and to other inertia effects. Resistance due to inertia is proportional to the square of the velocity of flow, while resistance due to viscosity is proportional to the first power of the velocity. Viscosity effects are predominant in the case of small quantities, thin films, low velocities, and of thick fluids. Inertia effects are predominant in the case of thin fluids, especially those of high specific gravity, fluids flowing in large masses, and fluids flowing at high velocities. Inertia effects are negligible in the case of bearing phenomena.

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Presented at the National Meeting of the Machine Shop Practice Division, Cincinnati, Ohio, September 24 to 27, 1928, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

To explain the effects of viscosity consider a cube of liquid as shown in Fig. 1. The face *ABCD* is moved in the direction of the arrow with a constant velocity, while face *EFGH* is fixed in position. The liquid will be sheared along every plane parallel with and lying between *ABCD* and *EFGH*, and the internal forces of the liquid will resist this shearing action.

Experiments show that with any given fluid the force required to move the face *ABCD* is directly proportional to the velocity, directly proportional to the area sheared, and inversely proportional to the thickness *AE*. It also varies with the temperature, usually being less as the temperature rises. The force in pounds required to shear an inch cube of a liquid at the rate of 1 in. per sec. is known as the absolute or dynamic viscosity of the liquid in the inch-pounds-second system. Scientists usually give the absolute viscosity of a liquid in C.G.S. units, or in dynes required to shear a centimeter cube at the rate of one centimeter per second under standard conditions.

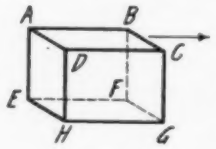


FIG. 1

The absolute viscosity, in either the C.G.S. system or the inch-pounds-second system, of a fluid suitable for use as a lubricant, is so small that it is not a practical unit of measurement. Accordingly the viscosity of a lubricant is usually expressed by the number of seconds required for a standard quantity of the lubricant to flow through a small tube of specified bore and length under standard conditions of head and temperature. Such a viscosity is nearly proportional to the absolute viscosity of the fluid.

Referring again to Fig. 1, let *EFGH* be a fixed plate having an area of S square inches, and *ABCD* a plate of equal area parallel to the first, and moving in its own plane with a velocity of V in. per sec. The thickness T of the film of fluid lying between the two plates is of course the distance *AE*. Then the force in pounds required to maintain the movement of plate *ABCD* at a velocity of V inches per second is:

$$F = \frac{KSV}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

The constant K is the absolute viscosity of the fluid and is

$$K = \frac{FT}{SV} \quad \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

It follows from Equation [2] that the physical dimensions of absolute viscosity are pound-seconds per square inch, or in C.G.S. units dyne-seconds per square centimeter.

Putting this equation into plain language, the following facts are obtained regarding the friction of fluid lubricated surfaces: (1) All other things being equal, the greater the area of the rubbing surfaces the greater the friction; (2) all other things being equal, the thinner the film of lubricant the greater the friction and consequently the higher the temperature at which the bearing will run; (3) all other things being equal, the higher the velocity of rubbing the greater will be the friction and the higher the temperature at which the bearing will run; and (4) all other things being equal, the more viscous the lubricant the greater the friction and the higher the temperature at which the bearing will run.

In any actual bearing, the area of the rubbing surface, the thickness of the film of lubricant, the velocity of rubbing, the viscosity of the lubricant, and the temperature of the bearing are not independent factors. The area of bearing surface, the viscosity of the lubricant, the load, and the velocity of rubbing all affect the film thickness, while the temperature of the bearing affects the viscosity of the lubricant. The problem becomes too complex for simple statement, or even for elaborate mathematical analysis, and must be solved by semi-empirical methods.

In order to understand more clearly what occurs in a copiously lubricated bearing, an endeavor will be made to develop an approximate physico-mathematical theory for a plain cylindrical bearing. Except for very short bearings this theory is a first approximation only, and its principal value lies in the fact that it serves to explain what occurs in a bearing under conditions of service. From this theory it may be learned how best to supply the lubricant, the best forms for oil grooves, where the wear will occur on the surface of the box, why suitable clearance is necessary in a bearing, and what the general effect will be if the load, the speed, the clearance, the viscosity of the lubricant, the length of the journal, or any other feature of design or operation be changed.

Fig. 2 shows a section in a plane of revolution of a cylindrical journal of radius r revolving in a cylindrical box of radius $r + c$,

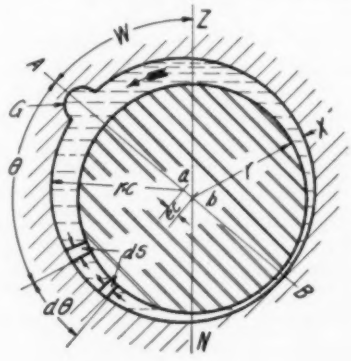


FIG. 2

where c is one-half the allowance for a running fit. This quantity c (or sometimes the allowance $2c$) is called the running clearance. The actual clearance, or the distance from a point on the surface of the journal to the nearest point on the surface of the box, is a very variable quality and it should not be thought of as being fixed when the box is machined.

Point a is the trace of the axis of the box and point b is the trace of the axis of the journal. The journal and box are not concentric, their centers being separated by the distance from a to b. This distance is designated by the symbol ec, where e is a proper fraction which is called the eccentricity ratio of the bearing. A variable quantity x is the distance at any point of the surface of the journal from the nearest point on the surface of the box, and is the film thickness of the lubricant at that point.

Assume that the weight of the journal and its load acts vertically along the line ZN, while line AB, making angle W with ZN, passes through the centers a and b. Assume a groove G, at the point where the film thickness is a maximum, to be continually filled with oil which wets both the journal and the box. As the journal revolves in the direction of the arrow, the oil tends to travel with the journal, and also to remain stationary with the box. The relative motion continually shears the oil, the velocity of any particular point in the oil film depending upon its relative distance from the surface of the moving journal and the stationary box. At the groove G, and also at the ends of the box, the average circumferential velocity of the oil will be one-half that of the journal. At all other points the variation in the static pressure of the lubricant (which is developed by the pumping action produced by the motion of the journal) tends to oppose or accelerate the rotation of the film of lubricant, so that its actual average circumferential velocity is less

than one-half the speed of the journal, and varies from point to point in a manner governed by mathematical relations so complicated that the general solution of the problem has hitherto defied analysis.

In order to simplify the theory let it be assumed that the velocity in the plane of rotation of any point in the film is proportional to its distance from the surface of the box, and that at the surface of the journal it is equal to the velocity of the journal. Hence the average velocity of rotation of the film is one-half that of the journal.

Consider an element or filament of the lubricant, distant angle Θ from line AB. Its thickness in a radial direction will be

$$x = c\ (1 + e \cos\Theta) \quad \ldots\ldots [3]$$

After this filament is moved the further angular distance $d\Theta$, the change in thickness will be

$$dx = -ec \sin\Theta\, d\Theta \quad \ldots\ldots [4]$$

If the length of the journal be L and the width of the filament be ds in each case, the change in volume will be

$$dU = Ldxds = -Ldsce \sin\Theta\, d\Theta \quad \ldots\ldots [5]$$

the minus sign indicating that the volume diminishes as Θ increases. The quantity of lubricant represented by this change in volume is squeezed out at the ends of the box, one-half being squeezed out at either end.

It will now be seen that in the case of such a bearing the revolving journal continually carries into the clearance space from the distributing groove G a sheet of oil whose mean speed is assumed to be one-half that of the journal. Since the space into which this oil is carried becomes steadily thinner, the sheet of oil is compelled to spread out at right angles to the direction of journal rotation, and the most of it is squeezed out at the ends of the box, between the groove G and the point of minimum film thickness. This action results in an axial component of flow. Sommerfeld, following the work of Reynolds, has developed a theory of lubrication of cylindrical bearings which ignores the axial flow, which is of course the theory of a bearing of infinite length. According to Sommerfeld's theory the mean circumferential velocity of the film at any element Θ_1 is to one-half the speed of the journal as the thickness of the film at the element where the maximum pressure occurs is to the thickness of the film at element Θ_1. According to Sommerfeld's theory the pressure of the lubricant is constant along the whole length of any element, being the same at the ends as at the center. It would follow from this that the allowable load is strictly proportional to the length of the bearing, and that circumferential grooves in the box have no adverse effect. Such is not the case, and Sommerfeld's theory leads to erroneous conclusions regarding the effect of oil grooves and the allowable loads on short bearings. Sommerfeld's theory, however, is of value in giving the limiting pressure which can occur at the center of any element of a long bearing.

In flowing endwise through the clearance space a back pressure is set up which varies from point to point over the surface of the box. This fluid pressure supports the journal so that it floats on a moving film of oil. The effect of the rotation of the journal is to produce a pumping action which maintains the fluid pressure that supports the shaft.

To investigate the axial component of the velocity of flow, and the amount of pressure which may be set up by this action, if $2w$ is assumed to be the angular velocity of the journal, then w will be the angular velocity in radians per second of the lubricant. The time required for the filament of lubricant which has already been considered to move the angular distance $d\Theta$ will then be $\frac{d\Theta}{w}$. Dividing the change in volume by twice the area of the filament multiplied by the time, the mean value of the axial component of the velocity with which the oil flows from the end of the journal at any point will be obtained. Solving the following equation results:

$$\frac{dU}{2\,xds\,\dfrac{d\Theta}{w}} = \frac{-Ldsce \sin\Theta\, d\Theta\, w}{2\ c\ (1 + e\cos\Theta)\ ds\ d\Theta} \quad \ldots\ldots [6]$$

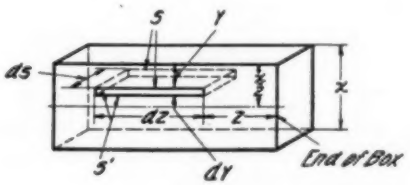


FIG. 3

Clearing this the following is obtained for the mean axial velocity of the lubricant at any point at the ends of the box:

$$\overline{V} = \frac{L}{2}\, w\, \frac{e \sin\Theta}{1 + e \cos\Theta} \quad \ldots\ldots [7]$$

We will now investigate the effect of this axial flow of lubricant in producing a hydrostatic pressure sufficient to lift the shaft. In Fig. 3 is shown an axial section greatly enlarged, through the filament of lubricant already considered. The filament is flowing endwise from the center section of the box and the portion considered is flowing to the right and lies to the right hand of the center of the box. Out of this filament a very small portion bounded by transverse planes and surfaces S and S' is taken. The length of the portion in an axial direction is dz, the width in a circumferential direction (i.e., perpendicular to the plane of a paper) is ds, as before, and the thickness in a radial direction is dy, the distance between surfaces S and S'. The difference in pressure in pounds per square inch at the two ends of the portion is dP.

Since the thickness of the filament is x, and the distance from the surface of the journal to the surface S of the element is y, the distance from the center of the filament to the surface S of the element is $\left(\frac{x}{2} - y\right)$. At the center of the filament the axial velocity is a maximum, dropping off to zero at the surface of the box or the journal. The axial shearing force at the center of the filament parallel to S is zero. At S the shearing force in pounds per square inch is

$$\frac{F}{A} = \frac{d\,Pds\left(\frac{x}{2} - y\right)}{dsdz} = \left(\frac{x}{2} - y\right)\frac{dP}{dz} \quad \ldots\ldots [8]$$

From Equation [1] the shearing stress in pounds per square inch is

$$\frac{F}{A} = \frac{KV}{T} \quad \ldots\ldots [9]$$

Substituting for T the value dy, and for V the value dv, which is the difference in velocity between the surfaces S and S'

$$\frac{F}{A} = \frac{KdV}{dy} = \left(\frac{x}{2} - y\right)\frac{dP}{dz} \quad \ldots\ldots [10]$$

Transposing [10]

$$K\,dV = \frac{dP}{dz}\left(\frac{x}{2} - y\right)dy \quad \ldots\ldots\ldots\ldots\ldots [11]$$

Integrating [11] between the corresponding limits of V = zero when y = zero and $V = V$ when $y = y$

$$KV = \frac{dP}{dz}\left(\frac{xy}{2} - \frac{y^2}{2}\right) \quad \ldots\ldots\ldots\ldots\ldots [12]$$

Solving for V, the axial velocity is obtained at any point distant y from the box or the journal.

$$V = \frac{1}{K}\frac{dP}{dz}\left(\frac{xy}{2} - \frac{y^2}{2}\right) \quad \ldots\ldots\ldots\ldots\ldots [13]$$

In order to obtain the mean velocity from the center of the filament to the surface of the box or journal, i.e., from y = zero to $y = x$ we may write

$$\overline{V} = \int_0^{\frac{x}{2}} \frac{V dy}{\frac{x}{2}} = \frac{2}{x}\int_0^{\frac{x}{2}} V dy \quad \ldots\ldots\ldots\ldots [14]$$

Substituting [13] in [14]

$$\overline{V} = \frac{2}{x}\int_0^{\frac{x}{2}} \frac{dP}{Kdz}\left(\frac{xy}{2} - \frac{y^2}{2}\right)dy \quad \ldots\ldots\ldots\ldots [15]$$

By transposing this becomes

$$\overline{V} = \frac{dP}{Kxdz}\int_0^{\frac{x}{2}} (xydy - y^2dy) \quad \ldots\ldots\ldots\ldots [16]$$

Integrating

$$\overline{V} = \frac{dP}{Kxdz}\left[\frac{xy^2}{2} - \frac{y^3}{3}\right]_0^{\frac{x}{2}} \quad \ldots\ldots\ldots\ldots [17]$$

Substituting the limiting values this becomes

$$\overline{V} = \frac{dPx^2}{12\ Kdz} = \frac{x^2}{12\ K} \times \frac{dP}{dz} \quad \ldots\ldots\ldots\ldots [18]$$

Equation [7] gives the mean axial velocity of the filament of the lubricant at a point distant $\frac{L}{2}$ inches from the center of the box. At a point z inches from the edge of the box the quantity $\frac{L}{2} - z$ may be substituted for the quantity $\frac{L}{2}$ and the following equation results

$$\overline{V} = \left(\frac{L}{2} - z\right)\frac{we\,\sin\Theta}{1 + e\,\cos\Theta} \quad \ldots\ldots\ldots\ldots [19]$$

which gives the mean axial velocity of the lubricant at any point on the surface of the box, between the elements of maximum and minimum clearance. Equating [18] to [19] and substituting the quantity $c(1 + e\,\cos\Theta)$ for x, we have

$$dP\,\frac{c^2(1 + e\,\cos\Theta)^2}{12\ K} = wce\,\sin\Theta\left(\frac{L}{2} - z\right)dz \ldots [20]$$

Integrating both sides of this equation between the corresponding limits of P = zero and $P = P$ and $z = 0$ and $z = z$,

$$P\,\frac{c^2(1 + e\,\cos\Theta)^2}{12\ K} = wce\,\sin\Theta\left(\frac{Lz - z^2}{2}\right) \ldots [21]$$

Solving this equation for P

$$P = 6K\,\frac{w}{c^2}\,\frac{e\,\sin\Theta}{(1 + e\,\cos\Theta)^2}\,(Lz - z^2) \quad \ldots\ldots [22]$$

This equation gives the value of the hydrostatic pressure P of the lubricant at any point distant angle Θ from the element of maximum clearance, and distant z inches from the nearest end of the box, the values of L, e, K, w, Θ, and c being as previously given.

It is now in order to determine the effect of changes in length of the bearing on the amount and distribution of this hydrostatic pressure. In order to do this then may be substituted for z in Equation [22] the quantity bL, where b is a factor which may have any value between zero and one-half, being zero at the end of the bearing and one-half at the center. This gives

$$P = 6K\,\frac{w}{c^2}\,\frac{e\,\sin\Theta}{(1 + e\,\cos\Theta)^2}\,L^2\,(b - b^2) \quad \ldots\ldots [23]$$

If now there is a series of bearings of different lengths (i.e., with different values of L), points having the same values for Θ and b, that is located at the same angular distance from the A-B axis and the same proportion of the length from the center of the bearing, will be homologous points. If one series of homologous points are taken, the function b is the same for each of the bearings and the factor $(b - b^2)$ may be represented by B. Substituting B in equation [23] and combining the constants,

$$P = K'BL^2\,w\,\frac{e\,\sin\Theta}{c^2\,(1 + e\,\cos\Theta)^2} \quad \ldots\ldots\ldots [24]$$

An inspection of this equation shows that at homologous points in two or more short bearings, when the other variables are equal, the hydrostatic pressure is proportional to the square of the length of the bearing.

The load-carrying capacity of a bearing is equal to the integral of the vertical components of the hydrostatic pressures acting on all of the several areas of the bearing. Since these pressures for different bearings are proportional to the squares of the lengths, and since the areas of the bearings are proportional to the lengths, it follows that the load-carrying capacity of a bearing is proportional to the cube of the length, when the diameter, speed, eccentricity ratio, and running clearance of the bearing are fixed.

An inspection of Equation [24] shows that for any given eccentricity ratio, the curve of pressure distribution for different angles in any particular plane perpendicular to the axis of a bearing is of the same form, whatever the viscosity of the lubricant, the length of the bearing, the point along the length chosen, the speed of the journal, and the operating clearance of the bearings. The form is, however, a function of the eccentricity ratio of the bearing. This follows from the fact that Equation [23] may be divided into two factors, one of which is

$$\frac{6\,K\,(b - b^2)\,L^2}{c^2}$$

while the other is

$$\frac{e\,\sin\Theta}{(1 + e\,\cos\Theta)^2}$$

The first factor is independent of the angular position of the point considered while the second factor is a somewhat complicated function of the eccentricity ratio and of the angular position of the point considered. So long as the eccentricity ratio of the bearing remains constant, the pressure at any particular

TABLE 1 COMPUTED FROM EQUATION [24]

	$E = 0.4$			$E = 0.6$			$E = 0.7$			$E = 0.8$			$E = 0.9$		
Θ	P	$P \sin \Theta$	$P \cos \Theta$	P	$P \sin \Theta$	$P \cos \Theta$	P	$P \sin \Theta$	$P \cos \Theta$	P	$P \sin \Theta$	$P \cos \Theta$	P	$P \sin \Theta$	$P \cos \Theta$
20	5.35	1.83	5.0	5.4	1.85	5.1	75.2	1.8	4.9	5.2	1.8	4.9	4.95	2.04	4.65
40	11.60	7.45	9.9	12.5	8.04	9.6	12.2	7.8	9.4	12.3	7.8	9.5	12.0	7.70	9.20
60	20.00	17.30	10.0	23.6	20.4	11.8	24.2	21.0	12.1	24.2	21.0	12.1	25.4	22.00	12.70
80	32.30	31.80	5.62	43.8	43.2	7.6	48.0	47.2	7.4	53.1	52.3	9.2	57.1	46.3	10.0
100	49.20	48.40	− 8.50	82.2	81.0	− 14.2	104.0	102.5	− 19.1	124	122.0	− 21.6	201.0	198.0	− 36.6
120	67.50	53.50	−33.70	152	132	− 76	217.0	188.0	−109.0	321	278.0	− 160.0	467.0	405.0	− 234.0
140	77.4	49.70	−59.20	245	157	−187	450.0	289.0	−345.0	890	572.0	− 682.0	1930.0	1240.0	− 1480.0
160	56.9	19.50	−53.40	247	84.5	−232	589.0	201.0	−554.0	1800	635	−1690	8330.0	2850.0	− 7830.0
165	45.0	11.60	−43.40	213	55.2	−206	528.0	137.0	−510.0	1850	479.0	−1790	10530	2730.0	−10180.0
170	31.2	5.40	−30.70	154	26.8	−152	404.0	67.0	−398.0	1460	254.0	−1440	10500	1820.0	−10330.0
175	16.0	1.40	−15.90	80.5	7.0	− 80	216.0	19.0	−215.0	823	71.8	−820.0	7130	621.0	− 7100.0
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean values		26.1	14.8		61.2	55.8		95.7	117.8		185.6	314.0		514	1432

point in the bearing depends on its distance from the end of the bearing, and is proportional to the operating viscosity of the lubricant and the speed of rotation of the journal, and inversely proportional to the square of the operating clearance.

From Equation [24] Table 1 has been computed. In this the quantity P is proportional to the pressure at a series of points in any given plane of rotation of the bearing, and is computed for different values of the eccentricity ratio ranging from $e = 0.4$ to $e = 0.9$, using the formula

$$P = \frac{100\ e \sin \Theta}{(1 + e \cos \Theta)^3} \qquad [25]$$

The value of $P \sin \Theta$ and $P \cos \Theta$ for different values of e and Θ are then computed, and by means of Simpson's rule, the mean value of the components of P perpendicular to and parallel to the AB axis are computed for each value of e. The load itself, which is proportional to the resultant of these components, is taken as the square root of the sum of the squares of the two mean components so found. Since the direction of the load is in the ZN axis, by dividing the component perpendicular to the AB axis by the resultant of both components, the sine of W is obtained.

In Table 2, column 1 are given different values of the eccentricity ratio, in column 2 the corresponding components of the load perpendicular to the AB axis, in column 3 the components of the load parallel with the AB axis, in column 4 angle W, and in column 5 the resultants of the perpendicular and parallel components, or the loads on the bearing. As the load increases from 30 to 1570, the value of e increases from 0.4 to 0.9. When the load is small the point of maximum clearance is about 60 deg. from the vertical in the direction of rotation and the point of minimum clearance about 60 deg. from the bottom of the box. As the load increases the angle W diminishes so that at the highest load computed, when $e = 0.9$, the point of minimum clearance is only 20 deg. from the bottom of the box.

In order to illustrate the angular distribution of pressure in accordance with this theory, values of P for different values of Θ have been plotted from Table 1 in Fig. 4. P is represented by the radial distance from the circle which represents the journal, to the outer line which represents the limit of P. It has been plotted for values of the eccentricity ratio of $e = 0.6$, $e = 0.7$, $e = 0.8$, and $e = 0.9$. In the first three cases the length of the scale line represents 500 units pressure. In the last case, however, the same length of line represents 2000 units pressure, so that the radial scale for $e = 0.9$ is only one-quarter as great as it is for the other three cases. In Fig. 5 is shown graphically the relation between the eccentricity ratio and the load, as plotted from Table 2.

TABLE 2 VARIOUS VALUES COMPUTED FROM TABLE 1

e	$F \sin W$	$F \cos W$	W deg.	W min.	F
0.4	26.1	14.8	60	28	30.0
0.6	61.2	55.8	42	51	83.5
0.7	95.7	117.8	39	4	151.9
0.8	185.6	314.0	30	36	364.8
0.9	514.0	1432.0	19	5	1570.0

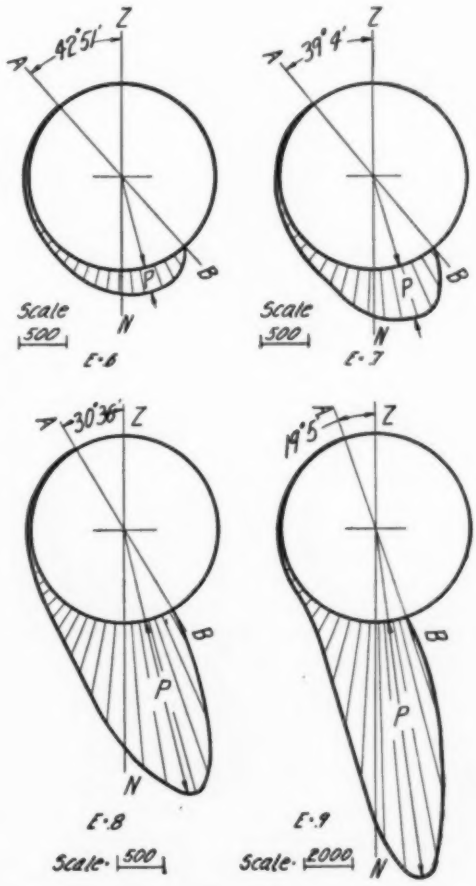


FIG. 4

These curves show graphically a number of things, among them that the pressure increases very rapidly for high values of the eccentricity ratio, that for high values of the eccentricity ratio the pressure is concentrated along a small portion of the surface at the bottom of the box, and that the effect of the pressure over the greater portion of the left-hand side of the box is only to prevent the journal from moving to the left and therefore to maintain the angle W at its proper value.

The curves in Fig. 4 show that with high values of the eccentricity ratio the maximum pressure occurring in a bearing may be many times greater than the mean pressure obtained by dividing the load by the product of the length and the diameter. Under such conditions the localized pressure may become so great as to cause the material of the box to flow, particularly if the box be formed of some plastic material like babbitt. This will result in a readjustment of the pressure distribution in such a manner as to give lower localized pressures. The box, however, will no longer be truly cylindrical and the mathematical

portion of the theory will no longer be tenable. Probably one of the advantages of a bearing metal having a low compression yield point is the fact that under the conditions of service it adjusts itself in such a manner as to give a more equal pressure distribution and a greater minimum film thickness.

It may be pointed out that from the point where the intensity of pressure is a maximum to the point of minimum clearance (point B), where the pressure becomes zero, the change in pressure tends to assist instead of oppose the rotation of the film of lubricant. At point B the lubricant flows past the surface of the box at a speed greater than one-half the speed of rotation of the shaft. This phenomenon, which is ignored in this mathematical theory, is analogous to one already noted, namely, that the lubricant rotates at less than one-half the speed of the shaft in the region where the pressure is increasing rapidly with increasing values of Θ. The effect of this phenomenon is to reduce angle W and to concentrate the pressure just in front of the region of minimum clearance.

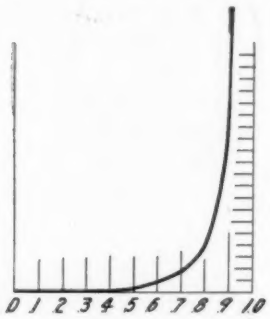


FIG. 5

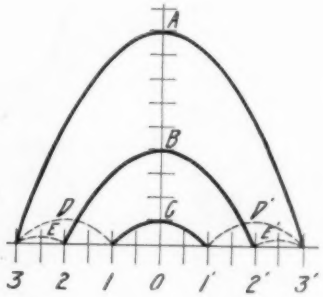


FIG. 6

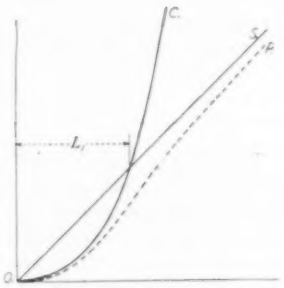


FIG. 7

In Fig. 6 is shown the relation between the pressure and distance measured along the axis of bearings 2 in., 4 in., and 6 in. long. It will be seen from these curves that the load-carrying capacity, which is proportional to the area under the curve, increases very rapidly with the length, in the case of a short bearing. It will be interesting to compare the relation between length and load-carrying capacity shown by the theory of short bearings and that shown by Sommerfeld's theory.

Referring to Fig. 7, horizontal distances represent bearing lengths, while vertical distances represent load-carrying capacities. The line OS, which is a straight line passing through the origin, represents the relation between the load-carrying capacity and the length of the bearing according to Sommerfeld's theory. Line OC, which is a cubical parabola, represents the relation between the length and the load-carrying capacity of a bearing in accordance with the theory of short bearings. It will be noted that the two lines cross at the point where the length is L_1. For lengths less than L_1 the theory of short bearings gives lower values for the load-carrying capacity, while for lengths greater than L_1, Sommerfeld's theory gives lower values for the load-carrying capacity. The actual load-carrying capacities of bearings are less than the values given by ordinates to the line OC for bearings shorter than L_1, and less than the values given by ordinates to the line OS for bearings longer than L_1, because of the combined effects of end leakage (which is neglected by Sommerfeld's theory) and the effect of the pressure differential in restraining the circumferential flow (which is neglected in the theory of short bearings). Consequently the true load-carrying capacities of bearings will follow some such line as the dotted line OP, which is tangent to line OC at the origin, is asymptotic to line OS, and lies entirely below both of them.

According to some computations made by Prof. E. O. Waters the length L_1 will lie somewhere between 1 and $1^1/_2$ times the diameter of the shaft.

In this connection it may be pointed out that a circumferential groove in the surface of the bearing has the same effect as though the bearing were divided by the groove into two parts. For instance, in Fig. 6 a bearing having the relative length of 6 has a load-carrying capacity proportional to the area included under the curve 3A3. If two circumferential grooves are cut at points 2 and 2′, distant 1 from each end, the load-carrying capacity of the bearing will be reduced to the area included under the three curves 3E2′, 2B2′, and 2′E′3′. In the same way if these grooves are moved to the points 1 and 1′, the load-carrying capacity will be still further reduced to that included under the three curves 3D1, 1C1′, and 1′D′3′.

In order to conserve the lubricant it is desirable to cut circumferential grooves near the ends of the bearing. These grooves catch the oil which flows out at the ends and return it to the groove G. These grooves should, however, be cut close to the edge of the bearing so that the effective length of the bearing will be a maximum.

An inspection of Table 2 and Fig. 5 shows a very interesting relation between the load on the bearing, which is designated by the symbol F, and the eccentricity ratio. This may be expressed very closely by the equation

$$F = 14.86 \frac{e^{0.3711}}{(1-e)^{2.041}} \quad \ldots\ldots\ldots\ldots\ldots [26]$$

or approximately, by the equation

$$F = K \frac{e^{0.4}}{(1-e)^2} \quad \ldots\ldots\ldots\ldots\ldots [27]$$

The factor K depends upon the units employed, the dimensions of the bearing, the speed of the journal, and the viscosity of the lubricant. The figure 14.86 is merely the particular factor which fits the conditions which form the basis of Table 2. For the purpose of computation this equation may be written in the form

$$\log F = 1.1719 + 0.3711 \log e - 2.041 \log (1-e) \ldots [28]$$

Another interesting relation is that between the running clearance and the value of e for a given value of the load. For a given eccentricity ratio the load will be inversely proportional to the square of the running clearance. An equation of the following form may, therefore, be written:

$$F = K \frac{e^{0.4}}{c^2(1-e)^2} \quad \ldots\ldots\ldots\ldots\ldots [29]$$

In this equation the function c (1-e) is the minimum film thickness. Solving for the minimum film thickness, an expression is obtained of the form

$$c(1-e) = K\frac{e^{0.2}}{\sqrt{F}} \quad [30]$$

It is probable that in usual bearings the value of e ranges from 0.7 to 0.9. Consequently, the fifth root of e will range from 0.932 to 0.979, a range of only about 5 per cent.

It is apparent from Equation [30] that the value of the minimum film thickness is practically independent of the value of c, the running clearance, and varies inversely with the square root of the load.

It is probable that a bearing fails when the minimum film thickness becomes too small. If such is the case, the value of the minimum film thickness under operating conditions is the most important factor determining the load-carrying capacity of a bearing. The minimum film thickness and therefore the load-carrying capacity are sensibly independent of the running clearance and it follows that the running clearance may theoretically have any reasonable value greater than about three times the allowable minimum film thickness. However, there is an operating clearance which will give the most satisfactory condition for a given speed and diameter of bearing. In general, longer bearings should have larger operating clearance than short bearings, and within reasonable limits the effect of too much or too little clearance may be counteracted by using a lubricant of high or low viscosity.

Small values for the running clearance give a bearing which is inclined to run hot and in which small changes of temperature will produce considerable changes in the running clearance. Moreover, if small running clearances are adopted, very small tolerances are necessary in order to avoid tight bearings. For many reasons it is desirable that the running clearance should not be reduced to the minimum at which the bearing will operate satisfactorily, under perfect conditions.

From the theoretical standpoint there is no reason why the running clearance should not be quite large. There are, however, many practical objections to a "loose" bearing. A loose bearing will necessarily have a high value for the eccentricity ratio, and hence the oil pressure will be concentrated along a narrow zone near the bottom of the box. When there are variations in the speed or in the direction of the load, a loose bearing will give more or less trouble.

For bearings of the usual speeds and diameters the minimum value of the allowance for a running fit may be taken as

$$2c = 0.0001\sqrt{D \times \text{r.p.m.}} \quad [31]$$

in which D is the diameter of the journal in inches, $2c$ is the minimum allowance for running clearance, and r.p.m. is the speed of the journal in revolutions per minute. The maximum allowance for good work is about twice this amount.

For speeds of less than 100 r.p.m. the allowance should be

$$2c > 0.001\sqrt{D} \quad [32]$$

The above allowances are the result of practical experience, but are in general in accordance with the theory as developed.

Certain general considerations regarding the design and operation of bearings can be deduced by means of the theory developed. If it is assumed, as seems reasonable, that the minimum film thickness is the most important of the factors which determine whether or not a bearing will operate successfully, conclusions embodied in the following rules are arrived at.

1 The load-carrying capacity of a bearing is proportional to its diameter.

2 The load-carrying capacity is proportional to the operating viscosity of the lubricant, i.e., to the viscosity of the lubricant at the temperature which the lubricating film attains in operation.

3 The load-carrying capacity is proportional to the speed of rotation in revolutions per minute.

4 The load-carrying capacity of a bearing is proportional to the surface speed of the journal, since this is proportional to the product of the diameter and the speed in revolutions per minute.

5 The load-carrying capacity of a bearing is a function of its length. For very short bearings such as eccentric straps, the theory developed in this paper is substantially correct, and it is proportional to the cube of the length. For very long bearings Sommerfeld's theory is substantially correct and it is proportional to the length. For bearings of the usual proportions, the load-carrying capacity is a function of the length approximately proportional to some power of the length greater than the first and less than the third. The load-carrying capacity of a bearing may possibly be represented by an empirical equation of some such form as

$$F = KL^{\left(\frac{3}{aL+1}\right)} \quad [33]$$

in which a is a constant.

The power loss in a bearing depends upon the eccentricity ratio. With the same operating clearance, operating viscosity, and speed, a bearing with a high eccentricity ratio will have a greater power loss than one with a low eccentricity ratio. If it is assumed that the eccentricity ratio remains constant, the following general rules are obtained.

6 The power loss in a bearing is proportional to the square of the diameter.

7 The power loss in a bearing is proportional to the length.

8 The power loss in a bearing is proportional to the square of the speed in revolutions per minute.

9 The power loss in a bearing is proportional to the square of the surface speed of the journal.

10 The power loss in a bearing is inversely proportional to the operating clearance.

11 The power loss in a bearing is proportional to the operating viscosity of the lubricant.

The preceding rules lead directly to the following conclusions regarding the ultimate rise in temperature of a bearing operating continuously with a given eccentricity ratio.

12 The rise in temperature of a bearing is independent of its length.

13 The rise in temperature of a bearing is proportional to its diameter.

14 The rise in temperature of a bearing is proportional to the operating viscosity of the lubricant.

15 The rise in temperature of a bearing is proportional to the square of the number of revolutions per minute.

16 The rise in temperature of a bearing is inversely proportional to the running clearance.

The 16 rules for the general behavior of a bearing which have been given assume that all the factors except the one considered remain constant. However, two or more factors usually vary at the same time, and any factor which varies affects in some degree the eccentricity ratio of the bearing. These rules are therefore not to be taken as a numerical expression of the behavior of a bearing, but rather as a guide to the general effect of variations in these factors. For instance a high-speed bearing usually has a larger running clearance than a low-speed bearing, so that although the increased speed tends to increase the power loss and the operating temperature, the increased

running clearance tends to produce an opposite effect. In considering the effects of diameter it must be remembered that bearings of large diameter have correspondingly large running clearance, and the rules regarding the effect of diameter and running clearance on power loss and operating temperature should be read in the light of this fact.

The 16 rules, the theory developed in this paper, and in a still larger measure, Sommerfeld's theory, also assume certain conditions which are never realized in practice, namely, that the box and the journal are both truly round and perfectly smooth, that they are rigid and maintain their shape, and that their axes are parallel and not affected by deflections produced by the load. On account of the effect of deflection an increase in the diameter of the bearing will be of greater practical value in increasing the load-carrying capacity than the rules indicate, while an increase in the length of the bearing will be of less value than the rules indicate. Because of imperfections in roundness and uniformity small operating clearances are less satisfactory than the rules would indicate.

The phenomena which occur in the operation of a bearing are so complex, and the several variables are so interrelated, that only the most general conclusions can be drawn concerning the behavior of bearings from such a mathematical theory as has been developed. When to these considerations is added the fact that practical bearings depart from their theoretical form both because of imperfections of manufacture and lack of perfect rigidity in the parts, it is found that their behavior is apt to be somewhat erratic, and the rules derived are indicative merely of the general trend of their behavior.

Discussion

MAYO D. HERSEY.[2] Many of the sixteen conclusions offered in this paper are not new and can be derived by elementary methods without the aid of the mathematical equations developed herein. This criticism applies especially to the conclusions regarding power loss, since the author has not ventured to outline any method for calculating the frictional resistance of a bearing.

In so far as the author's results are new, he has not attempted to show how they compare with the results of previous investigators who were attacking the same problems. This applies particularly to the new relations connecting pressure distribution with eccentricity, such as Equation [25], by means of which conclusions are finally drawn regarding the load-carrying capacity.

From this point of view the most important previous investigation is that of Sommerfeld[3] on which the subsequent work of Harrison and of Howarth[4] was based. I would like to suggest that the author continue his study to the extent at least of obtaining a comparison between his own equations for pressure distribution and those of Sommerfeld. Such a comparison will be very enlightening because of the physical difference in the basic assumptions from which both investigations proceed.

Thus Sommerfeld neglected longitudinal oil flow and considered only the pressures resulting from complex circumferential movements of the oil. Cardullo goes to the opposite extreme, building up his entire theory on the phenomena of the longitudinal flow, and deliberately neglecting all circumferential movements that cannot be described as a uniform-velocity gradient across the film at any one point. This assumption is introduced on the page where the author states, "In order to simplify the theory, let it be assumed, etc."

In the absence of experimental proof the reader is left entirely up in the air and cannot very easily judge whether Sommerfeld's assumption or Cardullo's assumption is nearer to the truth. The latter, of course, may be entirely possible.

To show that there is a real difference, reference may be made to the writer's paper[5] published in 1914 on "The Laws of Lubrication of Horizontal Journal Bearings." Equation [18] of that paper is based upon the same assumption as made by Cardullo, namely, the uniform velocity-gradient assumption; although the principal conclusions of the paper do not involve Equation [18] but are obtained by dimensional analysis, and are therefore entirely free from any specific assumption as to the character of the oil flow. Equation [19] is an expression of Petroff's law for the frictional resistance of a bearing with concentric journal, a relation that may be accepted without question as exact. It seems unnecessary to reproduce the two formulas here. Now it will be noted that upon dividing one by the other a formula is obtained for the relative friction of an eccentric journal as compared to that of a perfectly concentric journal under the same operating conditions (i.e., same load, speed, and oil viscosity). This relative friction may be written

$$R_c = \frac{1}{\sqrt{1 - e^2}} \qquad [34]$$

in which e denotes the eccentricity ratio as defined by Cardullo. The subscript c has been introduced to indicate that this expression is the one that would have been obtained by Cardullo if he had actually worked out the necessary integrations for computing frictional resistance from the shearing stresses corresponding to his own assumption.[6]

From Sommerfeld's theory a similar relation[7] can be obtained which turns out to be distinctly different from Equation [34], viz., using subscript s for Sommerfeld,

$$R_s = \frac{1}{\sqrt{1 - e^2}} \cdot \frac{(1 + 2e^2)}{(1 + e^2/2)} \qquad [35]$$

Comparing Equations [34] and [35] it is seen that $R_c = R_s$ when $e = o$, but that in general R_c is less than R_s. In fact, at the other limit where metallic contact is about to take place so that $e = 1$, Cardullo's friction value will amount to only one-half of Sommerfeld's value.

The mathematical portion of this paper is an interesting application of the theory of longitudinal oil flow. If only some one could combine this analysis with Sommerfeld's analysis of circumferential flow, one might consider that a complete mathematical theory of the cylindrical bearing operating under thick film conditions had been produced. In the meantime every effort should be made to promote experimental research.

L. J. BRADFORD.[8] The author's development of his theory rests on assumptions some of which appear unjustified. These are:

1 That the velocity of the oil film in the plane of rotation is proportional to its distance from the surface of the box. This

[2] Physicist, Bureau of Standards, Washington, D. C. Mem. A.S.M.E.

[3] *Zeit. f. Math. u. Phys.*, vol. 50, 1904, pp. 97–155; see also Trans. A.S.M.E., vol. 37, 1915, pp. 193–195.

[4] "A Graphical Study of Journal Bearing Lubrication." Reprinted by the A.S.M.E. in a single pamphlet.

[5] Jour. Wash. Acad. Sci., vol. 4, 1914, pp. 542–552.

[6] The necessary integration of the element of arc divided by film thickness will be found in a paper by the present writer in *Electrical World*, vol. 56, 1910, pp. 434–436, Eqs. 9–13. (See Fig. 1.)

[7] By combining Equations [43], [69], and [70] of the writer's paper in Trans. A.S.M.E., vol. 37, 1915, pp. 167–202.

[8] Professor of Machine Design, Pennsylvania State College, State College, Pa.

would be true if there were no flow due to differences in pressure within the film. There are, however, large differences in pressure in the film, and oil will flow from the higher pressure to the lower. This velocity of flow due to pressure difference must be either added to or subtracted from the velocity due to viscous drag on the journal and will modify the resultant velocity considerably.

2 The assumption that the quantity of lubricant represented by the change of volume of a filament in passing from the region of maximum clearance to that of minimum clearance is squeezed out at the ends of the bearing. Why cannot some of this lubricant flow in the plane of rotation? The probability is that it does.

The error of neglecting circumferential flow due to pressure differences results, among other things, in the curves of axial pressure distribution, as shown in Fig. 6, being much too sharp. When these pressures are measured on a testing machine the curve is found to be much flatter.

In calling attention to the effects of oil grooves upon the carrying capacity of bearings the author is performing a valuable service. This effect is not thought of by the average designers or mechanics, and the more it can be brought to their attention the better. Lubrication of bearings has been a matter of guesswork too long.

H. A. S. Howarth[9] and S. J. Needs.[10] We wish to call attention first to the fact that A. G. M. Michell, in his paper "The Lubrication of Plane Surfaces" published in *Zeit. f. Math. u. Phys.* in 1905, determined mathematically the influence of side leakage upon the load-carrying capacity and upon the friction of flat inclined bearing surfaces of different ratios of width to length. He assumed constant viscosity throughout the film. He examined the square surface and also the one that was three times as long as wide. He also determined in his "Case III" the leakage influence for a very narrow surface by making the same assumptions as to flow that Cardullo does in this paper.

The method employed by Michell will be evident from the following discussion of Reynolds' fundamental equation:

$$\frac{d}{dx}\left(h^3\frac{dp}{dx}\right)+\frac{d}{dz}\left(h^3\frac{dp}{dz}\right)=-6\mu U\frac{dh}{dx}\qquad[36]$$

This is the equation that must be applied fully to journal bearings if the problem of side leakage is to be correctly solved. In it x is measured in the direction of relative motion; z is at right angles thereto and takes account of the width of the film; h is the film thickness; μ is the coefficient of viscosity; U is the relative velocity of the surfaces; and p is the pressure within the film at any point x, z.

Reynolds in his further study of actual cases, such as flat bearing surfaces and Tower's journal bearing, assumed that the second term of Equation [36] could be dropped out. This gave:

$$\frac{d}{dx}\left(h^3\frac{dp}{dx}\right)=-6\mu U\frac{dh}{dx}\qquad[37]$$

which is the basis of the work of Sommerfeld, Harrison, Howarth and others, in the examination of various bearings. This equation permits calculation of the maximum pressures that can be obtained in a film of known shape and thickness. Michell, however, used Reynolds' Equation [36] complete in the study of square and three-by-one surfaces, and obtained the first general correct solution of the problem of side leakage for flat surfaces.

Then in his "Case III" Michell dropped the first term of Equation [36] and used:

$$\frac{d}{dz}\left(h_3\frac{dp}{dz}\right)=-6\mu U\frac{dh}{dx}\qquad[38]$$

for the study of *very narrow surfaces*. He says, "This simple expression may be used as an approximation for slide-blocks whose length is several times greater than their width." By application of Equation [38] Cardullo's final equations can be obtained without any of the elaborate reasoning he used in order to get to the same place. It is doubtful whether Cardullo was familiar with the equations of Reynolds or the work of Michell. However Cardullo applied his reasoning to what has previously been called the 180 deg. "offset" journal bearing, and although that was a relatively simple matter, he has emphasized the relatively low carrying capacities of *very narrow journal bearings*. The main problem is to decide how far his figures are useful, and to see whether a better rule is available.

For a given film, fixed in form and thickness, the application of Reynolds' Equation [37] will give a maximum pressure p that can be developed within the film, neglecting side leakage. Obviously if side leakage is taken into account the maximum pressure cannot reach p. Hence the pressures obtained by Cardullo can be laid aside as useless, when they exceed the maximum pressure predicted by Harrison when using Reynolds' Equation [37]. Cardullo's pressure equation for the midsection of the bearing in direction of motion is, using Harrison's symbols, c = eccentricity factor; $a = D/2$ = journal radius; η = radial clearance:

$$p_c=\frac{3\,\mu\,U\,c\,L^2\sin\Theta}{4\,a\,\eta^2\,(1+c\cos\Theta)^2}\qquad[39]$$

This becomes maximum when

$$\cos\Theta=\frac{1}{4c}\left(1-\sqrt{24c^2+1}\right)\qquad[40]$$

From Harrison the pressure equation applicable to the 180-deg. bearing of the "offset" series is found to be as follows:

$$p_H=\frac{6\,\mu\,U\,a\,c\sin\Theta\,(2+c\cos\Theta)}{\eta^2\,(2+c^2)\,(1+c\cos\Theta)^2}\qquad[41]$$

This becomes maximum when

$$\cos\Theta=-\frac{3c}{2+c^2}\qquad[42]$$

Hence Cardullo's bearing can be compared with the 180-deg. "offset" bearing, for any given eccentricity, by means of the above equations. After finding the maximum p_c and the maximum p_H, by using for each its proper value of Θ, p_H maximum can be equated with p_c maximum and L/D solved for. (L = bearing width.)

Then the relative capacities of the bearings can be found and the results plotted on a chart having as ordinates[11] the term $\frac{W}{\mu N}\left(\frac{\eta}{a}\right)^2$ and as abscissas L/D. Upon such a chart one may plot for $c = 0.3$ curves, based on Michell's study of the square surface and the three-by-one surface, that will show the approxi-

[9] H. A. S. Howarth, Vice-Pres. & Gen. Manager, Kingsbury Machine Works, Inc.

[10] S. J. Needs, Engineer of Tests, Kingsbury Machine Works, Inc.

[11] w = load on the bearing in lb. per sq. in., found by dividing the total load by the product of the journal diameter times the axial width of the bearing.
N = r.p.m. of journal.

mate influence of side leakage for all L/D proportions up to and beyond $L/D = 4$. Such a curve would show that Cardullo's equations are approximate only for very narrow surfaces. Even then they are on the high side; i.e., they give capacities that are greater than the true capacities of narrow bearings found by the correct method.

The range of usefulness of Cardullo's equations depends upon the eccentricity. The greater the eccentricity, the less the range. For example, Cardullo's capacities would not be unreasonable for values of L/D up to those given in the following table:

$c = 0.8$	$L/D = 0.15$
$c = 0.5$	$L/D = 0.42$
$c = 0.3$	$L/D = 0.62$

If bearings usually run with high eccentricities, 0.8 to 0.9 or more, as Cardullo states, then his equations would be needed most for such bearings and would be reasonably correct for values of L/D less than 0.15, very narrow bearings indeed.

What is needed now is the *correct* solution of Reynolds' *general* Equation [36] as applied to journal bearings of known forms and characteristics. It is to be hoped that some one will be able to solve that problem in the near future so that we may not be faced with further approximations that have such a limited range of application as that offered by Cardullo.

E. O. Waters.[12] It is a pleasure to read a paper on lubrication which states in clear and emphatic form the desirable properties of fluid lubricants. In the past, there has been a tendency to overemphasize viscosity, to the disparagement of other qualities of equal importance. This may well be due to the ease with which viscosity may be measured, at least in a comparative way, and the fact that this is the only property of an oil, outside of its density, which has any place in the mathematical analyses that have been developed during the past half-century, and now occupy a secure position in the literature of fluid friction. The trouble with all such analyses is that they assume (*a*) perfect film lubrication, and (*b*) constancy of viscosity, whereas, as a matter of fact, all bearings start up with metal-to-metal contact, many bearings run continuously in the boundary region that borders on metal-to-metal contact; and the numerical value of the viscosity of the lubricant in any given bearing is subject to considerable change due to temperature and localized regions of high pressure.

As a matter of fact, "oiliness," or the tendency to wet metal bearing surfaces at all times, is all-important in the boundary field of lubrication, and deserves further investigation. At the present time, specifications for lubricants are extremely hazy on this point, and there is a tendency for the producers of lubricating oils and greases to disdain a specification that calls for nothing but viscosity, high flash point, low volatility, etc., when they know full well that other properties less easily definable are quite as important. Would it not be well to investigate the surface tensions of lubricants, with the idea of including this among other specifications as a measure of the oiliness or wetting property?

Coming to the mathematical portion of the paper, it is evident at the outset that the author has discarded the classical analysis and followed a distinctly different line of reasoning, basing his equations on the assumption that the pressure in the bearing is caused entirely by axial motion of the fluid. The method followed by Reynolds, Sommerfeld, and others assumes, it will be remembered, that the fluid motion is wholly tangential. Obviously, both lines of reasoning are open to criticism; the classical method neglects the end leakage that occurs in all bearings and is critical in very short bearings, and Mr. Cardullo's analysis gives excessively high pressures for bearings of great length. In fact, Equation [23] of the paper indicates that the unit pressure on a bearing increases as the square of the length so that the total load sustained by a bearing of only moderate length would be of the order of infinity.

A common-sense analysis of the problem, without resort to mathematics, would indicate that at the center of any cylindrical bearing, the oil will be continually dragged from a region of low pressure and large clearance to one of high pressure and small clearance, and in squeezing through this small clearance it will speed up in the direction of least resistance, i.e., along the shortest and steepest pressure gradient. In short bearings, this would be toward the two ends, but in all other cases it would be a composite motion, and in long bearings it would apparently be easier for the oil to "escape" by travelling around the shaft to the low-pressure region, than to flow along it to the distant ends.

A rough comparison of the load capacities obtained by the two methods for a square bearing (length = diameter) may be of interest. Let $e = 0.6$, $w = 3.68$ rad. per sec., $L = 2$ in., $r = 1$ in., $c = 0.001$ in., and $k = 3.4 \times 10^{-6}$ lb-sec. per sq. in., corresponding to 150 sec. Saybolt. Then according to Equation [22], the unit pressure at any point is

$$P = \frac{6 \times 3.4 \times 10^{-6} \times 3.68}{0.000001} \times \frac{0.6 \sin \theta}{(1 + 0.6 \cos \theta)^3} (Lz - z^2)$$

$$= 75 \times \frac{0.6 \sin \theta}{(1 + 0.6 \cos \theta)^3} (Lz - z^2)$$

The total pressure on a filament of 1 in. width measured circumferentially, extending from end to end of the bearing and from the surface of the journal to that of the bearing, is:

$$2 \int_0^{\frac{L}{2}} P dz = 75 \times \frac{0.6 \sin \theta}{(1 + 0.6 \cos \theta)^3} \times \frac{L^3}{6}$$

$$= 100 \times \frac{0.6 \sin \theta}{(1 + 0.6 \cos \theta)^3}$$

According to Tables 1 and 2, this corresponds to a carrying capacity of $F = 83.5$ lb. per inch of circumferential length of bearing. Since the bearing diameter is 2 in., and the pressure must be sensibly zero over one half the circumference, from the point of closest approach around to the oil groove, Fig. 6, the total carrying capacity is $83.5 \times \pi = 263$ lb.

The problem of the partial bearing has been attacked by Howarth[13] according to the classical method. Here, the carrying capacity depends not only on the variables considered in Cardullo's analysis, but also upon the angle between the load line and the entering and leaving edges of the bearing. For a "central" bearing, in which the above angle is 90 deg., the carrying capacity may be obtained from his Fig. 30, and is found to be 1.2 lb. per sq. in. of projected area per r.p.m. Since the assumed speed is 3.68 rad. per sec. for the oil, or $\frac{3.68 \times 60 \times 2}{2 \pi}$ = 70.3 r.p.m. for the journal, and the projected area is 4 sq. in. the total carrying capacity of the bearing would be $1.2 \times 4 \times 70.3 = 338$ lb.

Time and space do not permit of a further study along these lines, but it may be assumed that the figure of 338 lb. should be considerably reduced because the load line is offset upward of 47 deg. from the central position. (See Fig. 4.) At any rate the

[12] Assoc. Prof. of Mechanical Engineering, Yale University, New Haven, Conn.

[13] "A Graphical Study of Journal Lubrication. (Part II)" Trans. A.S.M.E., vol. 46, p. 809.

load ratings for the square bearing as calculated by the two methods are roughly equivalent, but for any shorter bearings the Cardullo formulas would give much smaller values than those obtained by the classical method. This would seem to be in agreement with common sense, and perhaps some empirical formula like [33] in the paper may be devised to cover both long and short bearings. However, the writer believes that it should be held in abeyance until well corroborated by experimental data.

Author's Closure

Most of the discussion of this paper is contributed by men whose knowledge of mathematics and of the literature of bearings far exceeds that of the author. It is not necessary to point out that the author's theory is not complete and correct, because it is pointed out in the paper itself.

In developing his theory the author has made certain assumptions not in accordance with the facts, but no other bearing theory accords with facts, and even Reynolds' fundamental equation, which has hitherto defied a general solution, and which is discussed by Messrs. Howarth and Needs, accords only with geometrical assumptions which are never realized in practice.

There are in general two ways to attack a scientific or engineering problem. The first is to develop a general equation, such as Reynolds' fundamental equation, and then *if possible* to solve this equation by purely mathematical manipulation. If the general equation is correct and the solution is obtained, we have an answer which may or may not be approximately correct, depending upon how important the factors are which were necessarily eliminated in order to obtain a manageable general equation. For instance, the factors eliminated from Reynolds' general equation are variations in diameter of the shaft and the box, bending of the shaft, lack of parallelism of the axes of the shaft and the box, and local irregularities in the surface of the box produced by variations in the hydrostatic pressure. Even though we had a solution of Reynolds' general equation, we would still be a long way from answering the question of the best design for a bearing.

While the general method is favored by most men of high mathematical attainments, the author prefers to attack a problem in detail, examining and analyzing each element separately and in its relation to the other elements, in order to get a vivid physical concept of the problem. To a mathematician this appears to be a clumsy and inelegant method, but it is exactly the method which the practical engineer must use when he is dealing, not with mathematical concepts, but with imperfect materials machined to imperfect forms, and acted upon by forces which distort the forms from those to which the materials were originally machined.

Frankly, this paper is not a presentation of a mathematical theory of a bearing. It is, instead, a general discussion of the phenomena occurring in thick film lubrication of cylindrical bearings, in which the mathematical theory is brought into the picture, not to obtain an arithmetical solution of the problem, but to illuminate the phenomena which occur and to make clear their interrelation.

While much excellent work has been done on the subject of bearings, most of it has been so purely empirical as to be of value only in the immediate region investigated, or else so purely theoretical that the great majority of designers are incapable of comprehending it, the mathematics being divorced as far as possible from the physical concepts which they express.

The author has endeavored to make his paper helpful to the average designer of mediocre mathematical attainments, and to link each step of the mathematical development with the physical concept with which it is associated. In order to do this, a simplified theory is necessary, and the author has chosen the particular simplification of the general theory which lends itself most readily to his purpose.

The author would also like to point out that 95 per cent of the literature on the theory of thick film lubrication is practically inaccessible to the great majority of the members of the Society either because it is published in transactions or periodicals which are procured only with difficulty or because it is available only in an unfamiliar language. The author feels, therefore, that this paper and the accompanying discussion may be of some value in calling the attention of interested members of the Society to a body of literature which exists, and which is continually growing.

The author feels strongly that this body of literature should be rewritten in such form as to make it available, comprehensible, and useful to that body of engineers who have to do with the design of machine bearings and whose mathematical attainments, like those of the author, are limited to elementary calculus.

The author wishes there was available such a book, similar to the most admirable book on bearings compiled some years ago by one of our members, Mr. L. P. Alford, which, however, dealt with the subject almost entirely from the empirical standpoint and practically ignored the various theories of lubrication.

For lack of such a book most bearings are designed by purely empirical formulas which are useful within limited ranges, but which do not meet the needs of present-day engineering requirements.

MSP-52-13

Cutting Tests With Cemented-Tungsten-Carbide Lathe Tools[1]

By T. G. DIGGES,[2] WASHINGTON, D. C.

This investigation was made for the purpose of developing a method of testing cemented-tungsten-carbide lathe tools under heavy duty and to extend to the new cutting material some of the laws originally developed by Taylor and his associates for cutting with carbon- and high-speed-steel tools. Relations were determined between the speed, feed, depth of cut, and tool life for a selected form and size of tool. All tests were made dry in cutting 3.5 per cent nickel-steel forgings, heat-treated to give tensile strengths within the range of 85,000 to 110,000 lb. per sq. in. The results are presented in both graphic and tabular forms.

CEMENTED-tungsten-carbide tools were first placed on the market on a commercial basis in Europe in 1926 and in the United States several years later. The rapid development of this material during the past year has made possible its extensive use for tools throughout this country and abroad.

The records of production with these tools have already shown that this new cutting material will occupy a most important place in our industrial life.

The experiments described in this report relate primarily to a study of lathe-tool performance as affected by the conditions of cutting, such as variations in speeds, feeds, and depths, while the composition, the size, and the form of the tools and cutting materials were not varied. The investigation was for the purpose of developing a method of testing tungsten-carbide tools under heavy duty and to establish some of the laws of cutting which define the approximate relations between tests of short duration, which might be made in the laboratory, and long-time cutting required in practical service. The need of such information is shown by the large number of inquiries received by the Bureau of Standards from consumers.

Previous Investigations

No attempt will be made to review the abundant literature published since the introduction of tungsten carbide as a cutting material. The articles published have dealt primarily with outstanding production records and other phases not directly related to the field to be covered. Such data may be used to advantage, and important technical publications containing information on the subject under discussion will be referred to in the individual sections of this report.

Methods of Tests—Equipment

A 36-in. heavy-duty engine lathe, driven by a 40-hp. 220-volt d.-c. shunt motor, was selected. (See Fig. 1.) A Link Belt chain was used to insure a positive drive. Accurate speed control of the work piece was secured by using the several gearing ratios of the lathe and by changing the speed of the motor with a variable resistance in the field circuit. Experiments showed that it was necessary to increase the rate of speed of the motor in order to prevent excessive slowing down or stalling under heavy loads.

A special tool holder was designed to give ample support to the test tool near the cutting edge. This was firmly clamped in the four-bolt tool-post holder shown in Fig. 1.

A "live center" (tailstock) containing a ball bearing and having the form and dimensions shown in Fig. 2 was used instead

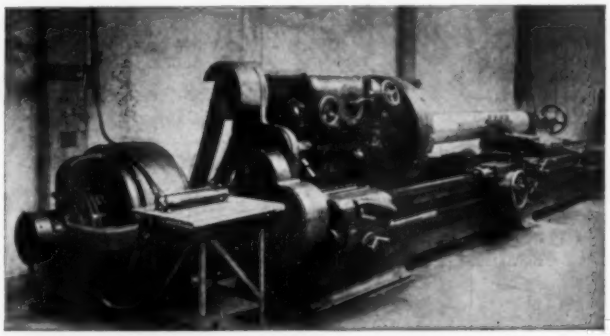


Fig. 1 Lathe Used in Tool Tests

of the customary "dead center." Its insertion required considerable time and labor, but it avoided lubrication troubles common with the "dead center."

A single-pointed cutting tool was selected, and its form was similar to that commonly employed for heavy-duty roughing work. Its form and dimensions, as shown in Fig. 3, consisted of tungsten-carbide tips approximately 0.18 in. thick, 0.31 in. wide, and 0.87 in. long, copper-brazed on a shank 0.5 in. wide, 1 in. thick, and 7 in. long. The tools had a plane angle of 90 deg. and were ground to 6 deg. front and side clearance, 0 deg. back slope, 14 deg. side slope, 10 deg. back side relief, and the radius of the nose was 0.0625 in. The edge of the tool from this arc along its cutting edge was ground to a contour of 1.75 in. radius for 0.4375 in. All tools were hollow ground to a depth of 0.003 to 0.006 in. at approximately 0.25 in. from the cutting edge of the tools. Special grinding wheels of silicon carbide were used for grinding the tools.

The tools used in this investigation were manufactured by the Carboloy Company, Inc., by certain sintering operations in which the fine particles of tungsten carbide were cemented firmly together with cobalt, and the material is referred to as cemented

TABLE 1 CHEMICAL ANALYSIS REPRESENTATIVE OF THE CEMENTED-TUNGSTEN-CARBIDE TOOLS

Lot no.	Chemical composition, per cent			
	C	W	Co	Fe
1.....	5.3	81.4	12.7	0.76
2.....	5.3	81.2	12.6	0.66

[1] Published with the approval of the Director, National Bureau of Standards, Washington, D. C.

[2] Associate Metallurgist, Bureau of Standards, Department of Commerce. Mr. Digges attended Virginia Polytechnic Institute and George Washington University, graduating from the latter institution with the degree of B.S. in physics. During the years 1918 and 1919 he was in active service in the United States Army. Since 1920 he has been associated with the Bureau of Standards.

Contributed by the Machine Shop Practice Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

tungsten carbide to differentiate it from the cast product. Chemical analyses were made on two lots of tungsten-carbide tools that were supplied at different times. Table 1 shows that the tools were quite uniform.

Procedure

From five to eight tools were tested for most of the conditions investigated, and all tests were made in sequence. For example, in the study of the effect of feed on tool performance, one tool was tested at each of the selected feeds in the series, a second tool was tested at each of the same feeds, and this procedure was continued until the desired number of tools had been tested for each condition. From one to three tests were made with each tool, but no tool after being reground was used under the same conditions of test as those under which it had formerly been tested. Only average values are used for comparisons in this report.

Testing tools in sequence has long been practiced and tends to minimize variations in results arising from inhomogeneities in the metal being cut. The pieces upon which the cuts were taken, referred to as forgings, were originally from 10 to 12 in. in diameter and from 8 to 10 ft. in length. In some cases the forgings were cut to diameters as small as 4.5 in. in the cutting tests. Average mechanical properties were determined on longitudinal specimens cut from the forgings so as to represent the average metal removed during cutting. The chemical composition, heat treatment, tensile properties, and Brinell hardness of the forgings are given in Table 2.

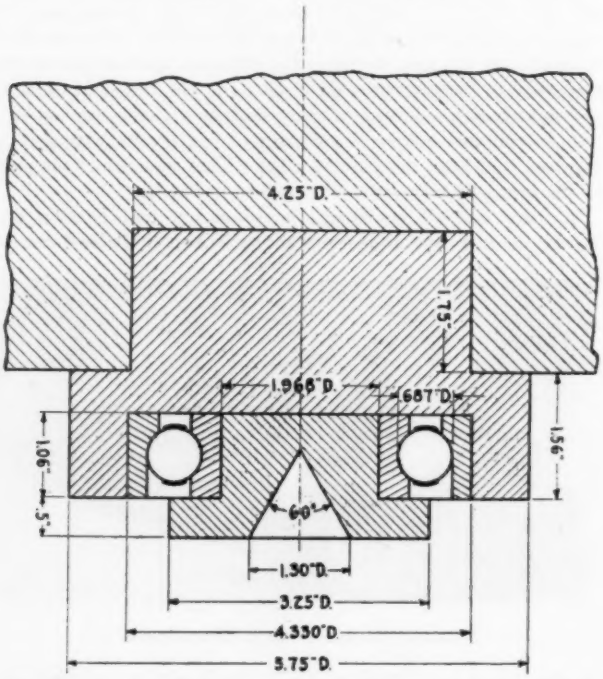


Fig. 2 Type of Tailstock Center Used in Lathe Tests

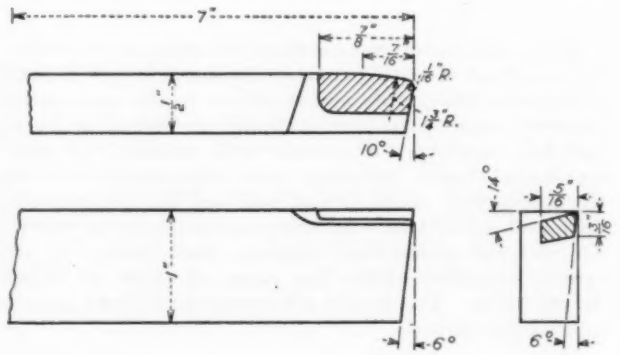


Fig. 3 Size and Form of Tool Used in Lathe Tests

In making a cutting test the tool was clamped so that its side was at right-angles to the longitudinal axis of the forging, with the end of the nose on dead center. The lathe was then set at the desired feed, the tool at the required depth, and the speed of the lathe adjusted to give the forging the desired peripheral speed. The tool was fed by hand until the desired cut was reached, after which the automatic feed was thrown in and the time recorded. The speed of the forging decreased when cutting began, but was quickly adjusted to bring it back to its original value. Before starting any test care was taken to remove any glazed surface on the forging caused by the breakdown of the previous tool or any particles of the tool that might have become embedded in the forging.

All tests were run dry, and the cutting speed, feed, and depth

TABLE 2 CHEMICAL COMPOSITION, HEAT TREATMENT, AND MECHANICAL PROPERTIES OF THE FORGINGS

Forging no.	Chemical composition, per cent C	Mn	P	S	Si	Ni	Cu	Heat treatment[a]	Proportional limit, lb. per sq. in.	Yield point, lb. per sq. in.	Tensile strength, lb. per sq. in.	Elongation in 2 in., per cent	Reduction of area, per cent	Brinell hardness number
44....	0.33	0.72	0.044	0.030	0.28	3.29	0.28	1480 deg. fahr. held 1½ hr.; furnace cooled. 1530 deg. fahr. held 3½ hr., and cooled in emulsion.[b] 1200 deg. fahr. held 3½ hr.; furnace cooled	81,500	86,500	106,300	26.0	61.3	230
45....	0.29	0.65	0.032	0.029	0.32	3.40	0.26	1540 deg. fahr. held 3½ hr.; cooled in emulsion. 1220 deg. fahr. held 2½ hr.; furnace cooled	68,500	76,000	100,000	25.5	60.2	202
52....	0.30	0.67	0.038	0.028	0.29	3.39	0.24	1520 deg. fahr. held 3½ hr.; furnace cooled	59,000	60,000	88,800	29.0	53.1	168
53....	0.30	0.61	0.026	0.037	0.26	3.43	0.24	1520 deg. fahr. held 3½ hr.; furnace cooled	50,000	51,000	84,200	29.5	47.5	163
54....	0.31	0.68	0.042	0.035	0.31	3.17	0.20	1500 deg. fahr. held 3½ hr.; furnace cooled	51,500	54,000	85,200	31.0	55.0	163
55....	0.30	0.67	0.034	0.033	0.29	3.37	0.22	1650 deg. fahr. held 3½ hr.; air cooled. 1480 deg. fahr. held 3½ hr.; furnace cooled	58,000	60,250	95,250	30.5	51.8	180
56[c]...	0.26	0.57	0.041	0.035	0.15	3.81	0.11	1650 deg. fahr. cooled in emulsion; 1560 deg. fahr. cooled in water; 1340 deg. fahr. air-cooled	41,100	49,200	85,600	27.5	55.1	166

[a] Chemical composition and heat-treatment data reported by manufacturer.
[b] The emulsion referred to consisted of 5 per cent rape seed oil, 15 per cent paraffin oil, and 80 per cent water containing 1 per cent sodium carbonate.
[c] Forging No. 56 was hollow-bored; hole approximately 5½ in. in diameter. Nos. 44 and 45 were hollow-bored; hole[illegible] in. in diameter.

of cut were varied, depending upon the purpose of each series of tests.

Tool Failure

A groove was formed on the top surface of the tool near the "leading edge" soon after the tool started to cut. This depression became greater as the test progressed until a condition was finally reached when the wear was sufficient to cause a small



Fig. 4 Depressions Worn on Top Surfaces of the Tools During Tests
(All tools had failed except tool shown on extreme left.)



Fig. 5 Wear on Front of Tools During Test
(All tools had failed except tool shown on extreme left.)

section to chip or break out of the working portion of the tool. This "end point" usually resulted in a glazed surface on the test forging and was often accompanied by a splitting of the chip, which gave an additional indication of tool failure. Thus there was a very definite end point and one that could be recognized without much difficulty. In some of the experiments, especially those of the most severe conditions of cutting, this end point was often quickly followed by, if not simultaneous with, tool breakage which would leave doubt as to the time of tool failure. Such doubtful tests were discarded in these experiments. In some cases it would have been possible to continue to cut after the described condition was reached, but only at the expense of badly broken tools. All cutting results given in this report were obtained by the "end-point" method described. The wear on the top and front surfaces of the tools at the time of failure is illustrated in Figs. 4 and 5.

The appearance of the forging at the time of failure of the tungsten-carbide tools was very similar to the appearance of a forging when a high-speed-steel tool fails under the so-called "lathe breakdown test." A glazed surface was produced on the forging at the bottom of the cut at the time of tool failure, as is shown in Fig. 6.

Effects of Cutting Speed on Tool Life

It is a well-known fact that the cutting speed of a high-speed-steel lathe tool is dependent upon the quality, composition, and heat treatment of the tool and on the properties of the metal cut, as well as upon the size and form of tool, feed, and depth of cut. It appeared reasonable to assume that the cutting speed of cemented-tungsten-carbide lathe tools should depend upon approximately the same variables as high-speed-steel tools, and it was upon this basis that the experiments were performed.

The results of tests at different speeds with a feed of 0.031 in. per revolution and depth of 0.1875 in. are summarized in Table 3 and Fig. 7. Fig. 7 shows that there was a continuous increase in the life of tungsten-carbide tools as the cutting speed was decreased. Within the life range of 9 to 156 minutes the experimental results may be represented by the empirical equation

$$VT^n = c \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

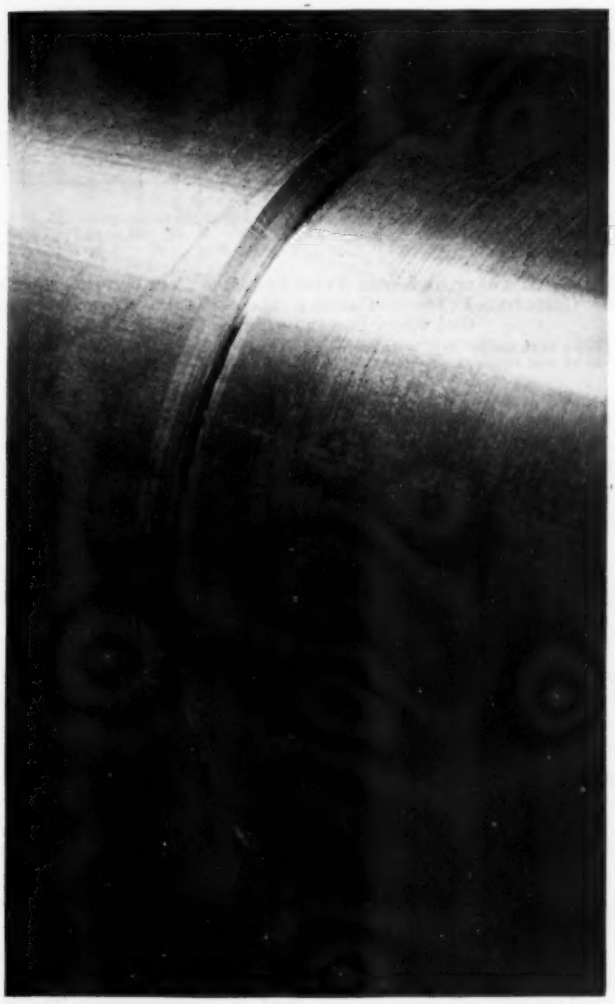


Fig. 6 Appearance of Test Forging at Time of Tool Failure
(Note the glaze at the bottom of the cut.)

in which V = the cutting speed in feet per minute
T = the tool life in minutes
c = a constant which is dependent upon the cutting conditions other than speed; it should vary with the form and size of tools, material cut, nature of tools, feed, and depth of cut
n = constant.

Taylor[3] found the effect of cutting speed on the tool life of

[3] F. W. Taylor, "On the Art of Cutting Metals," Trans. A.S.M.E., vol. 28 (1907), p. 31.

TABLE 3 EFFECT OF SPEED ON PERFORMANCE OF CEMENTED-TUNGSTEN-CARBIDE LATHE TOOLS

Forging no. [b]	Cutting conditions: Speed, ft. per min.	Feed, in. per rev.	Depth, in.	No. of tests	Average tool life, min.	Calculated [a] cutting speed ft. per min.	Average power required in cutting kw.
44 & 45.....	90	0.031	0.1875	5	155.9	93	4.1
44 & 45.....	110	0.031	0.1875	6	74.9	108	5.4
44 & 45.....	120	0.031	0.1875	6	45.9	119	5.5
44 & 45.....	130	0.031	0.1875	3	26.7	132	6.2
44 & 45.....	140	0.031	0.1875	6	21.2	139	6.4
44 & 45.....	160	0.031	0.1875	5	9.0	164	6.8

[a] Computed by means of equation $VT^n = c$ with $n = 1/5$ and $c = 255$.
[b] All tests were run dry with the size and form of tool shown in Fig. 3. See Table 2 for properties of forgings.

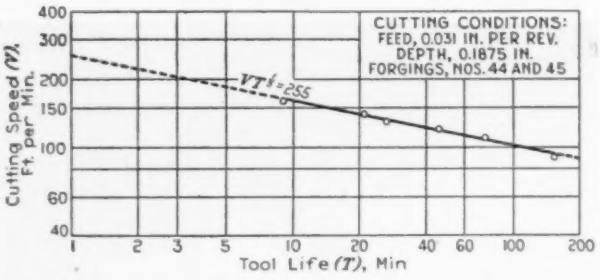


FIG. 7 SUMMARY OF LATHE TESTS SHOWING THAT CUTTING SPEED OF CEMENTED-TUNGSTEN-CARBIDE TOOLS VARIES INVERSELY AS ONE-FIFTH POWER OF THEIR LIFE

(Tests were made "dry" with form and size of tool shown in Fig. 3. Properties of test forgings given in Table 2. Note that logarithmic coordinates are used.)

high-speed steels could be represented by Equation [1]. This empirical relationship between tool life and cutting speed with high-speed-steel tools was recently confirmed by the Lathe Tool Research Committee[4] and by tests conducted at the Bureau of Standards,[5,6] and by Ripper and Burley.[7]

Taylor[3] reported cutting tests on carbon steels having a tensile strength of about 70,000 lb. per sq. in. with tools of definite size and shape made from steel containing about 1.9 per cent carbon, 8.5 per cent tungsten, and 2 per cent chromium. He found the value $n = 1/8$ and $c = 90$, but stated, "We have made a number of experiments . . . with different qualities of steel and find that approximately the same relation exists between the duration of cut and cutting speed for steels of different degrees of hardness. This statement, however, does not apply to cast iron."

Not all investigations have confirmed Taylor's value of the exponent n. Ripper and Burley[7] reported the value of $n = 1/13$, and French and Digges[8] in cutting tests with modern high-speed tools cutting $3\frac{1}{2}$ per cent nickel steel of about 100,000 lb. per sq. in. tensile strength reported $n = 1/7$ for roughing conditions (heavy duty) and $n = 1/10$ for finishing cuts (light duty).

Schlesinger,[9] in cutting experiments carried out at the Technological Institute at Berlin with high-speed steel and superhard metal tools in cutting a steel of approximately 100,000 lb. per sq. in. (Brinell number of about 190), found that the cutting-speed–tool-life curves for the super-hard metals had the same characteristics as those of high-speed steel. His data show that the relations between tool life and cutting speed for sintered-tungsten-carbide tools, where the cross-section of the chip was 0.158 by 0.039 in., could be closely represented by Equation [1] when $n = 1/4.3$. In another set of experiments which appear to have been carried out under the same test conditions, it was found that $n = 1/7.1$. With high-speed-steel tools n was found to be equal to about $1/8.3$, which is in close agreement to the value reported by the Bureau of Standards for roughing tests.

Examination of the results summarized in Fig. 7 shows that the experimental values obtained for sintered-tungsten-carbide tools were approximately represented by Equation [1] with $n = 1/5$. Therefore, the equation

$$VT^{1/5} = c \qquad [2]$$

was used for all computations in this report involving the relation between the cutting speed and tool life. There was a close concordance between the experimental results and the calculated values, and Equation [2] should be sufficiently accurate for all practicable purposes except for extrapolating for very long tool life from tests of short duration. It is of interest to note that this law as originally developed by Taylor and his co-workers was confirmed with the cemented-tungsten-carbide lathe tools

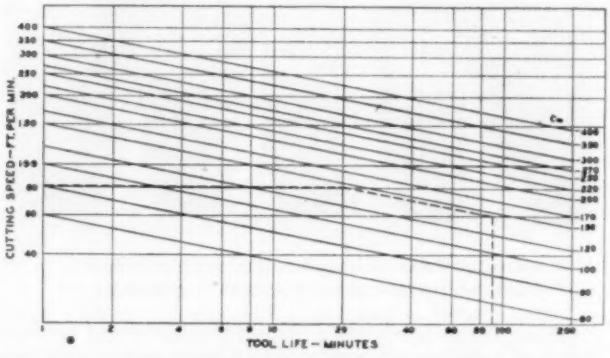


FIG. 8 CHART GIVING RELATION BETWEEN CUTTING SPEED AND TOOL LIFE

(Lines drawn according to Equation $VT^{1/5} = c$, in which V = cutting speed, T = tool life, c = constant.)

for duration of cut between 9 and 156 minutes under conditions widely different from those of Taylor's experiments.

Equation [2], which expresses the relation between tool life and cutting speed, is represented graphically by straight lines when logarithmic rectangular coordinates are used. The chart reproduced in Fig. 8 is of a convenient form for computing the life of tools at various speeds and makes it simpler to interpolate between the values of the constant c shown on the chart than would be the case with the curves obtained with Cartesian coordinates.

EFFECT OF FEED AND DEPTH OF CUT ON THE CUTTING SPEED

It is not practicable to select a single cutting speed for lathe-tool testing varying widely in either feed or depth of cut because of the expense of the large amount of material that would be involved and the time required to make such test. The cutting speed has already been shown to have an empirical relation to the tool life at a given feed and depth, so that in the study of the effects of feed and depth on tool performance the cutting speed was also varied. In general, cutting speeds giving an average tool life from 10 to 30 min. were selected, and then the

[4] Department of Scientific and Industrial Research, Manchester Association of Engineers, the 1922 Report of the Lathe Tool Research Committee, published by His Majesty's Stationery Office, London.

[5] H. J. French and T. G. Digges, "Rough Turning With Particular Reference to the Steel Cut," Trans. A.S.M.E., vol. 48 (1926), p. 533.

[6] H. J. French and T. G. Digges, "Turning With Shallow Cuts at High Speeds," Bureau of Standards, *Journal of Research*, vol. 3 (1929), p. 829.

[7] W. Ripper and G. W. Burley, "Cutting Power of Lathe Turning Tools," *Proc. Inst. Mech. Engrs.*, 1913, parts 3 and 4, p. 1967.

[8] Refer to footnotes 5 and 6.

[9] George Schlesinger, "German Practice With Tungsten-Carbide Tools," *American Machinist*, vol. 71 (1929), p. 37.

TABLE 4 EFFECT OF FEED ON PERFORMANCE OF CEMENTED-TUNGSTEN-CARBIDE LATHE TOOLS

Cutting conditions			Tool life, min.								Average power required in cutting, kw.	Cutting[a] speed for 90-min. tool life, ft. per min.
Forging no.[c]	Speed, feet per min.	Feed, in. per rev.	Depth, in.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Average	
52	160	0.031	0.1875	30.6	11.5	21.2	20.8	20.8	27.3	25.0	22.5	5.5	121
52	120	0.054	0.1875	26.9	31.0	27.3	40.5	12.2	26.4	[b]	27.4	7.1	94
52	105	0.078	0.1875	23.3	8.0	12.1	16.0	[b]	12.7	12.6	14.1	8.5	72
52	90	0.096	0.1875	16.7	14.8	19.3	[b]	9.1	16.7	[b]	15.3	9.3	63

[a] Computed from average tool life by means of Equation $VT^{1/5} = c$.
[b] Tool broke.
[c] See Table 2 for properties of forging.
All tests were run dry with the size and form of tool shown in Fig. 3.

TABLE 5 EFFECT OF DEPTH OF CUT ON PERFORMANCE OF CEMENTED-TUNGSTEN-CARBIDE LATHE TOOLS

Cutting conditions							
Forging no.[b]	Speed, ft. per min.	Feed, in. per rev.	Depth, in.	No. of tests	Average tool life, min.	Average power required in cutting kw.	Cutting speed[a] for 90-min. tool life, ft. per min.
53, 54, 55	200	0.031	1/8	8	17.7	5.7	144
53, 54, 55	180	0.031	3/16	8	15.1	7.2	126
53, 54, 55	160	0.031	5/16	8	14.4	11.8	111
53, 54, 55	150	0.031	7/16	7	18.5	16.6	109
53, 54, 55	140	0.031	9/16	7	16.5	20.6	100

[a] Computed from the average tool life by means of Equation $VT^{1/5} = c$.
[b] See Table 2 for properties of forgings.
All tests were run dry with the size and form of tool shown in Fig. 3.

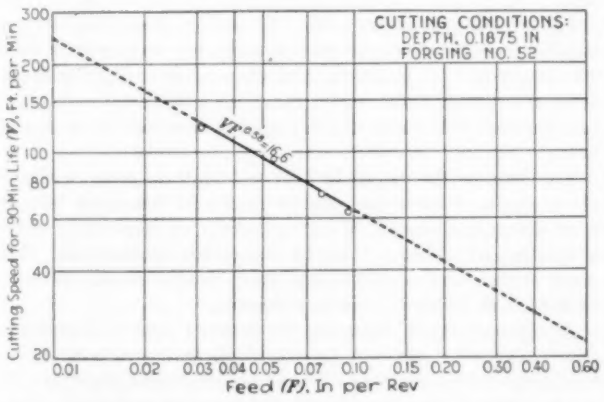


FIG. 9 SUMMARY OF LATHE TESTS SHOWING EFFECT OF FEED ON CUTTING SPEED FOR A 90-MIN. TOOL LIFE

(Tests were made "dry" with form and size of tool shown in Fig. 3. Properties of forging given in Table 2. Line drawn according to Equation $VF^{0.58} = 16.6$, in which V = cutting speed for 90-min. tool life, ft. per min.; F = feed, in. per rev.)

cutting speeds for the desired tool life were computed by means of Equation [2].

Two series of tests were made with the cemented-tungsten-carbide tools in order to establish the relations between the cutting speed, feed, and depth of cut. One was made with a constant depth of cut of 0.1875 in. and feeds ranging from 0.031 to 0.096 in. per revolution, and the other with a constant feed of 0.031 in. per revolution and depths of cut ranging from 0.125 to 0.5625 in.

The results of the tests made with a constant depth of cut and variable feeds are given in Table 4, and the cutting speeds for a 90-min. tool life with the different feeds used in the experiments are summarized in Fig. 9. As shown in Fig. 9, the relation between the cutting speed and the feed for a given tool life at a constant depth of cut may be represented approximately by the relation

$$VF^m = c_1 \quad \ldots\ldots [3]$$

in which V = cutting speed in feet per minute for a selected tool life
F = feed in inches per revolution
c_1 = constant
m = constant

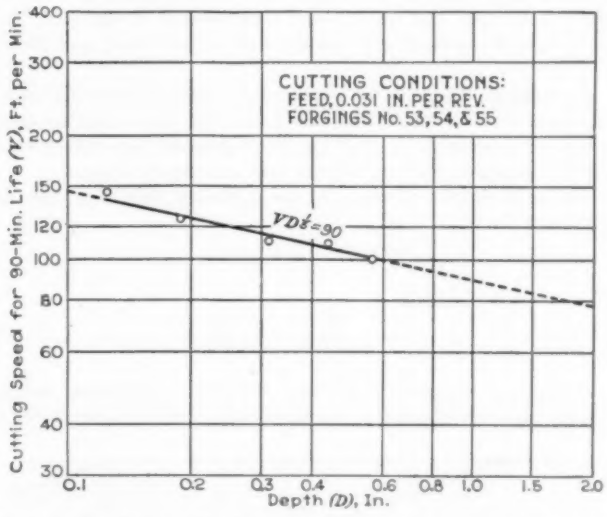


FIG. 10 SUMMARY OF LATHE TESTS SHOWING EFFECT OF DEPTH OF CUT ON CUTTING SPEED FOR A 90-MIN. TOOL LIFE

(Tests were made "dry" with form and size of tool shown in Fig. 3. Properties of forgings given in Table 2. Line drawn according to Equation $VD^{1/5} = 90$, in which V = cutting speed for 90-min. life, ft. per min.; D = depth of cut, in.)

When operating with cutting speeds for a selected 90-min. tool life at a 0.1875 in. depth of cut in cutting 3.5 per cent nickel-steel forging having a tensile strength in the neighborhood of 85,000 lb. per sq. in., the exponent m was found to be 0.58, with c_1 equal to 16.6. Substituting these results in Equation [3] gives

$$VF^{0.58} = 16.6 \quad \ldots\ldots [4]$$

The detailed results as recorded in Table 4 show a surprisingly close agreement between the individual tool performances. In a majority of the tests this variation was no greater than that ordinarily found when testing high-speed-steel lathe tools under heavy duty.

The results of the cutting tests made with a constant feed and variable depths are given in Table 5. The cutting speeds for a 90-min. tool life with the different depths used in the experiments are summarized in Fig. 10. The results show that there was a continuous increase in the cutting speed with a decrease in depth of cut and that the relation between the cutting speed and depth of cut with a constant feed and given tool life may be represented by the equation

$$VD^p = c_2 \quad \ldots\ldots [5]$$

in which V = cutting speed in feet per minute for a selected tool life
D = depth of cut in inches
c_2 = constant
p = constant.

It was found that p was equal to 0.2 and that c_2 was equal to 90, for a 90-min. tool life, and with a feed of 0.031 in. per revolu-

tion and depths of cut varying from 0.125 to 0.5625 in. Substituting these results in Equation [5] gives

$$VD^{0.2} = 90 \quad \ldots\ldots [6]$$

An examination of Fig. 10 shows that there was a close agreement between the experimental and calculated values over a wide range of depths of cut.

As already stated, the cutting speed for a given tool life is dependent upon the quality and composition of the tool, the properties of the metal cut, size and form of tool, feed, and depth of cut.

In these experiments the quality and composition of the tools, size and form of tools, and the metal cut were kept as near constant as possible so that the cutting speed for a given tool life was dependent only upon the feed and depth of cut.

From Equations [4] and [6] for a 90-min. tool life, there is obtained

$$VF^{0.58}D^{0.2} = K = 12 \quad \ldots\ldots [7]$$

or

$$V = \frac{K}{F^{0.58}D^{0.2}} = \frac{12}{F^{0.58}D^{0.2}} \quad \ldots\ldots [8]$$

The equations given in this report check experimental values closely and can be used as the basis for computing speeds for a

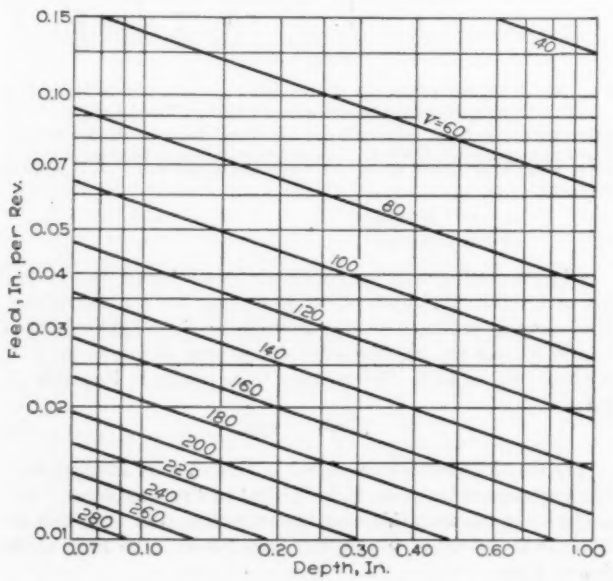


FIG. 11 CUTTING SPEED-FEED-DEPTH CHART FOR SELECTED SIZE AND FORM OF TOOLS AND CUTTING MATERIAL USED IN EXPERIMENTS

(This gives cutting speed for 90-min. tool life in dry turning 3.5 per cent nickel steel of approximately 85,000 lb. per sq. in. tensile strength at various feeds and depths. The maximum feed and depth values as shown on chart are greater than those that can be used with 1/2-in. by 1-in. cemented-tungsten-carbide tools. Refer to text for discussion of use of chart.)

selected tool life under varying conditions, provided the size, form, quality, and composition of tools and the type of cutting material herein described are used. If the tool life is known at some one speed, feed, and depth of cut, these computations require only the use of Equations [2] and [7]. The computations necessary in applying Equations [2] and [7] are, however, tedious because of the form of Equation [7], and to avoid these computations the chart reproduced in Fig. 11 was constructed. This chart is adopted for the reading of the various cutting speeds permitting a 90-min. tool life with various combinations of feeds and depth of cut. With the logarithmic rectangular coordinates used for depth of cut and feed, the cutting speed V (shown on the chart, Fig. 11) for 90-min. tool life is represented by straight lines.

In using this chart, find the intersection of the desired feed and depth coordinates. This point of intersection will usually fall between the sloping lines representing the cutting speed. This value will give the approximate cutting speed V for a tool life of 90 min. The cutting speed for a tool life within the range of 1 to 200 min. may be obtained from the charts reproduced in Figs. 11 and 8 or by Equations [7] and [2].

For example, if it is required to compute the cutting speed for a 90-min. tool life with a feed of 0.08 in. per revolution and 0.5 in. depth of cut, from Fig. 11 it will be seen that the 0.08 in. per revolution feed and 0.5 in. depth coordinates intersect at the speed line corresponding to 60 ft. per min. Now, if the cutting speed for 20-min. tool life with the same feed and depth of cut is desired, there is obtained the value of 81 as given by the chart shown in Fig. 8. This latter value is obtained by finding the intersection of the abscissa representing a tool life of 90 min. (follow the dotted line in Fig. 8) with the ordinate representing a cutting speed of 60 ft. per min., then by interpolating by following the straight line (shown in Fig. 8 as $c = 150$) until this line intersects the abscissas representing a tool life of 20 min.

Fig. 11 was constructed with the lines representing the permissible cutting speeds for 90-min, tool life, ranging from 40 to 280 ft. per min. at intervals of 20 ft. per min. Cutting speeds other than those shown on the chart for a 90-min. tool life may be estimated with a reasonable degree of accuracy by extrapolation.

The limits of the values for feed and depth as given in Fig. 11 are in excess of those that can be used with 0.5-in. by 1-in. cemented-tungsten-carbide tools. However, it is possible to use a wide range of feeds and depths of cut with this size tool. This chart should also be applicable (with modifications) to larger tools than those used in the experiments.

As already stated, Equation [7] does not take into consideration changes in size and form of tools and variations in materials cut. The need of such tests becomes immediately apparent in order to extend the relations between the relatively short-time laboratory test of this new cutting material to its wide field of industrial work.

As shown by Equation [7], the cutting speed is not affected equally by changes in feed and depth of cut. A higher cutting speed is more closely associated with a deep cut and fine feed than with a corresponding combination of coarse feed and shallow cut. Equations [2] and [6] show that the exponents n and p, expressing the relation between cutting speed and tool life and the cutting speed and depth of cut, are equal.

GENERAL COMMENTS ON THE LATHE TESTS

Despite the fact that cemented tungsten carbide contains appreciable proportions of cobalt, it is a relatively brittle material, and for this reason the cutting tools must be well supported. For these tests the carbide tips were joined to the tool shank by copper-brazing in a hydrogen atmosphere. Hoyt[10] stated: "It has been found that tungsten-carbide tips which are rigidly welded to the shank are only too apt to come off, either directly after the tool is made or after being put in service. This is due to thermal stresses which are set up by temperature changes and differences in the coefficients of expansion of the carbide and the steel. This circumstance accounts for the popularity of copper-brazing, because here the thin layer of copper affords a soft cushion which absorbs such stresses without

[10] S. L. Hoyt, "Tungsten-Carbide Tools Most Remunerative of Production Jobs," *Iron Age*, vol. 124 (1929), p. 1173.

transmitting them to the carbide tip. On the other hand, copper softens at elevated temperatures, so that it is necessary, in the design of the tool, to remove the joint far enough away from the cutting edge so that it does not get dangerously hot during operation."

This method of attaching the carbide tip was satisfactory for most of the conditions used in the cutting tests, although premature failure in several tests resulted because of the rupture of this bond.

The heaviest cuts used with the 0.5-in. by 1-in. tools were probably greater than those that could be used in ordinary shop practice where cost due to tool breakage becomes important. The carbide tips of the tools were reduced in size by grinding and weakened accordingly, so that most of the tool breakage was confined to the heaviest cuts with tools that had been reground. The test showed that the tools could be used under relatively heavy duty provided they were properly supported and not subjected to vibration.

The forces on a lathe tool, while cutting, are practically independent of the cutting speed and are dependent upon the cross-section of the chip. It is evident from this principle that tungsten-carbide tools should be used at relatively high speeds and for light cuts in order to keep tool breakage at a minimum. As shown by Equation [2], the cutting speed varies as the $^1/_8$th power of the tool life. This indicates that a small change in cutting speed causes a correspondingly large change in the tool life, so that the higher cutting speeds are obtained only at the expense of shorter tool life. The most economical cutting conditions must, therefore, be a compromise between several factors, such as increase in cutting speed with decrease in tool life and tool breakage, in order to remove the maximum amount of metal in the minimum time at the least cost.

Some idea of the relation between the cutting speeds associated with tungsten-carbide tools and high-speed-steel tools may be obtained from the cutting-speed–tool-life curves reproduced in Fig. 12. Attention is directed to the fact that the two curves were not made under identical conditions of cutting, and only a general comparison can be made from these results. For example, the tungsten-carbide tools are larger than those used in the high-speed-steel experiments, and the tool angles are different for the two types of tools.

The high-speed-steel tools were of the 18 per cent tungsten type, quenched in oil from 2400 deg. fahr., and tempered at 1100 deg. fahr. These tools were 0.25 in. by 0.5 in. in size and were ground to a front and side clearance of 6 deg., side slope of 8 deg., back slope of 14 deg., and a nose radius of 0.125 in. The cutting materials, as shown in Table 2, had approximately the same chemical and physical properties, but, as already pointed out, it does not necessarily follow that the two forgings have the same cutting properties. Both forgings were of the 3.5 per cent nickel type, heat-treated to give a tensile strength of about 85,000 lb. per sq. in.

Fig. 12 shows that considerably higher cutting speeds (under certain conditions) were obtained with the tungsten-carbide tools than with the high-speed-steel tools. Also, the slopes of the straight lines representing the relations between cutting speed and tool life with the logarithmic system of coordinates were different for the two types of tools. The slope of the curves obtained with the tungsten-carbide tools was greater than that obtained with the high-speed-steel tools. This means that the two curves tend to approach each other, and the differences between the cutting speeds of the two materials decrease with increase in tool life. If these curves are extrapolated to an extremely long tool life, then the curves will cross, and the high-speed-steel tools would show higher cutting speeds than the tungsten-carbide tools. However, such long-time cutting cannot be extrapolated with any degreee of accuracy from the present empirical equations, and it is also doubtful if cutting conditions resulting in such long tool life would ever be practicable in modern shops from an economical standpoint.

While the tungsten-carbide tools were considerably superior to those of high-speed steel in cutting 3.5 per cent nickel-steel forgings of about 85,000 lb. per sq. in. tensile strength, it does not follow that the same degree of superiority will be obtained under widely different cutting conditions, especially where heavy feeds and deep cuts are used. Therefore, it is necessary to know exactly the cutting conditions in order to make a comparison of the two types of tools.

No direct indication of the performance of the tungsten-carbide

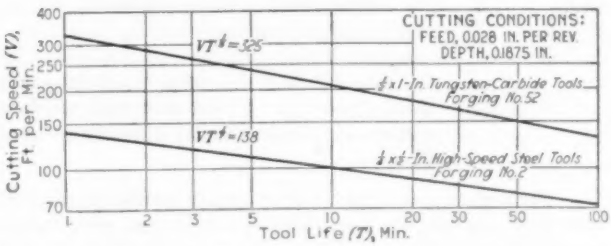


FIG. 12 SUMMARY OF RELATION BETWEEN CUTTING SPEED AND TOOL LIFE WITH TUNGSTEN-CARBIDE AND HIGH-SPEED-STEEL LATHE TOOLS

(Tests were run "dry" with the size and form of tools shown in report. Properties of forgings given in Table 2. For cemented-tungsten-carbide tools, line drawn according to Equation $VT^{1/8} = 325$. For high-speed-steel tools, line drawn according to Equation $VT^{1/8} = 138$, in which V = cutting speed, ft. per min.; T = tool life, min.)

tools could be detected by the types of chips produced in the lathe tests. In general, the chip came off in very long ribbons during the first part of the cut, and then became shorter with more curl as the cutting time increased, until a short time before tool failure the chips were approximately 0.5 to 1 in. in length. While these chips were characteristic for some of the conditions employed, especially with tools tested on forging No. 52, they were not characteristic of the tools tested under conditions of varying depths of cut on forgings Nos. 54 and 55. In the latter case, the long chips often continued until tool failure.

The power required in cutting was determined in all of the lathe tests with tungsten-carbide tools and was determined at frequent intervals throughout the life of the lathe tools, so that only average values were obtained. The instruments used, however, did not permit determinations of the fluctuations or the maximum momentary power consumption. The results given in Table 3 show that, at constant feed and depth of cut, the power was approximately proportional to the cutting speed. The exact relations between the feed and depth of cut and the power consumed cannot be established at this time. The results given in Tables 4 and 5 show that there was an increase in the power with increase in feed or depth. However, as already pointed out, the feed and depth experiments were not made at a constant speed, so that the magnitude of the changes in power due to changes in feed or depth cannot be established from the limited number of tests made. The power determinations are included with the test results in order to show that it is necessary to have machines equipped with powerful driving units in order to utilize the full capacity of tungsten-carbide tools.

SUMMARY AND CONCLUSIONS

1 The primary object of this investigation was to develop a method of testing tungsten-carbide lathe tools under heavy duty and to extend to the new cutting material some of the empirical laws originally developed by Taylor and his associates for rough turning with carbon- and high-speed-steel tools.

2 The so-called lathe breakdown test for high-speed steels was found applicable for testing cemented-tungsten-carbide tools under heavy duty.

3 The characteristics of the cutting-speed–tool-life curves for tungsten-carbide tools were similar to those of high-speed-steel tools.

4 In dry rough turning 3.5 per cent nickel steel of about 105,000 lb. per sq. in. tensile strength, with a constant feed, depth of cut, tool size, and form, the relation between cutting speed and tool life within the life range of 9 to 156 min. may be represented by the empirical equation

$$VT^n = c$$

where V = the cutting speed in feet per minute
T = the tool life in minutes
n = constant = $1/8$
c = constant which is dependent upon the conditions of cutting. It will vary with the form and size of tools, materials cut, feed, and depth of cut.

5 For a given area of cut, higher cutting speeds are obtained with deep cuts and fine feeds (within limits) than with shallow cuts and coarse feeds.

6 The relation between cutting speed, feed, and depth of cut in terms of the experimental conditions may be represented by the empirical equation

$$VF^{0.48}D^{0.2} = K = 12$$

in which V = the cutting speed for a selected tool life
F = feed in inches per revolution
D = depth of cut in inches
K = constant = 12 for the experimental conditions.

7 Higher cutting speeds are obtained with cemented-tungsten-carbide tools under certain conditions of cutting than with high-speed-steel tools.

8 Cemented-tungsten-carbide tools are brittle, but when properly supported will produce excellent results under certain cutting conditions.

9 High cutting speeds with relatively fine cuts are more favorable to the successful application of tungsten-carbide tools than heavy cuts at slower speeds.

10 Machines capable of operating at high speeds with powerful driving units are necessary to utilize the full cutting capacity of cemented-tungsten-carbide tools.

Acknowledgments

The author acknowledges the assistance and suggestions of Dr. S. L. Hoyt and W. E. Smith. The Carboloy Company, Inc., donated all tungsten-carbide test tools and the majority of test forgings.

Grateful acknowledgment is also due to Dr. R. L. Dowdell, senior metallurgist, for his aid and constructive suggestions in the presentation of the test data, to W. V. Magruder, Jr., laboratory aid, and C. F. Raab, machinist, formerly of the Bureau of Standards, for their assistance in assembling the equipment and for carrying out many of the tests.

Discussion

C. G. Williams.[11] At the present time, all of the noise about cemented-tungsten-carbide tools is in the nature of a selling propaganda and a smoke screen, as it were, to hide the inherent characteristics that at the present time prevent tungsten carbide from being the unalloyed success that it should be.

After carrying on experiments with Carboloy, Widia, and Diamondite, over a period of two years, in three shops, the writer arrived at the decision that none of these cutting metals can be a success used as they are in present machinery. Even in some of our latest machine tools, they cannot be made to give 100 per cent efficiency, and it is not so much the fault of the material itself as it is of the machine tools, which were not designed to give that stability and power, with absence of vibration, that are so essential to the proper use of these metals to get their true worth in a machine shop.

This has also been true of Haynes' Stellite, and this alone has been the one thing that has caused Stellite to remain unadopted as a cutting metal by the world today.

The proprietors of these high-speed cutting alloys are carrying on a selling campaign that should not begin at the shops of the users, but should begin in their own laboratories. They should tabulate their results, showing the failures as well as the successes, then analyze the failures to find out the "why." A corrective suggestion will soon follow.

The proprietors should advertise their failures as well as their successes, so that the man in the shop will not attempt the impossible and as a result jump at a hasty conclusion, as is usually the case, and give the metals a bad name. Within the last two years, the writer has seen failure after failure and has heard of many more that would have been avoided had the proprietors of these cutting metals carried out the foregoing suggestion.

The tests and demonstrations so far carried on have been good in so far as showing the inherent qualities for usefulness in the metals, but tests must now be made to demonstrate the adaption of these stunts to actual production methods, then to demonstrate those methods instead of the stunts.

At the present time the builder of machine tools could stand a lot of education to produce a machine tool that could successfully use cemented tungsten carbide, and a let-up on the shops and proprietors of shops should be in order until it is definitely known what the actual capabilities of these metals are under present shop methods and with present shop tools.

It will be three or four years at the least before designers can possibly become acquainted with the capabilities and faults of these metals and even longer than that if the proprietors continue to stress selling above actual worth demonstration to the makers of machinery.

At the present time the writer can get far better results on cast iron from the old chilled cast-iron tools of my boyhood shop experience than from the new cutting alloys, and in many cases can get far better results with chilled cast-iron tools on good grey iron than can be obtained with high-speed tools, and high-speed tools beat the new cutting alloys on this metal when used on modern machines. When it comes to the hard white iron, all of the tools, excepting chilled cast iron, fell down.

Ernest F. DuBrul.[12] It is only two years since we first heard vague rumors about some mystery metal that gave wonderful results as a medium for cutting metal.

At the Cincinnati boat-ride meeting, the writer stated that such a cutting metal meant another revolution in designs of machine tools and that both builders and users of machine tools would do well to recognize the necessity of research on which to base new designs.

The writer pointed out that the introduction of a new and revolutionary cutting material was certain to proceed much faster than was the case with high-speed steel. There is greater

[11] Chief Engineer, Barker Machine & Tool Works, Green Bay, Wis. Mem. A.S.M.E.

[12] General Manager, National Machine Tool Builders Association, Cincinnati, Ohio. Assoc. A.S.M.E.

open-mindedness in industry at the present time; there is also more exchange of information between the different factors in the situation. It was pointed out that if this introduction were fast and furious, but without a basis of good research information, it would be extremely costly. The suggestion was made that a fund of $250,000 should be subscribed for definite, coordinated research to save great waste that would occur otherwise.

By December of the same year we had learned so much more about these materials that the writer raised the research ante from $250,000 to $500,000. It was then evident that we were facing precisely such a revolution as was caused by high-speed steel. It was pointed out that when Frederick W. Taylor made his experiments in cutting metals, which extended over a period of years, he had spent $250,000 in the course of those experiments. But a dollar in the first decade of this century had at least twice the purchasing power that a dollar has today. So that a fund of $500,000 nowadays could only be expected to duplicate in research about what Taylor had secured for the larger purchasing power of the $250,000 that he had expended.

In the last year and a half there have been much experimenting, much duplication, much expense, and much delay. Failures were duplicated, and successes were not always duplicated, nor were the successes always reported as fast as would have been the case if this work were coordinated.

The lack of coordination has caused much designing which will have to be done over after more facts are known. The writer feels more sure than ever in saying that the machine-tool industry will have wasted much money before this revolution in design is over and that this waste will amount to far more than the $500,000 fund suggested.

At the time this suggestion was made the writer also suggested, and he repeats it now, that the users of machine tools would find it to their interest to put up this research fund as quickly as possible. Eventually the user will pay for this waste, so it is to the users' interest to get the right results as quickly as possible, and without all the delays that are now being suffered due to lack of coordination of this research. Some of the problems of this revolution are entirely too large for any individual company to attempt to solve by individual research.

As evidence of the fact that much information is required, Mr. Digges says that the need of the sort of information contained in this paper is shown by the large number of inquiries received by the Bureau of Standards from users of machine tools. Mr. Digges' paper is a valuable contribution to the subject, but after all it is quite limited in its scope, due to limitations in time, funds, and various other factors. It merely gives the results of tests on one kind of material with a limited number of tools. One is not told what the results would be on other materials or with other types of cutting tools.

The manufacturers of tungsten-carbide tools have discovered that different forms of tool shanks produce quite different results. They do not yet know the best forms to use.

Up to the present time it is not known how high a speed and how heavy a cut the tungsten-carbide tools will stand. No one knows definitely what is needed in the machine tool to get the highest speed and best cut possible with tungsten-carbide tools. A year ago at Rochester the writer asked Mr. Bausch how fast a diamond will cut on brass. His answer was: "We don't know. We are cutting a thousand feet a minute, which is as fast as the machine will cut without setting up chattering that breaks the diamond." Today, a year later, it is not known how fast the diamond will cut.

Some builders of machine tools are presumptuous enough to say that their new machines are fully up to the limit of tungsten-carbide tools. They make this statement in their sales literature. This is a presumptuous statement, because they do not actually know what the limits of tungsten-carbide tools are. They might get a rude awakening some day when the real limits of tungsten-carbide tools are determined by scientific tests, unless they would find merely as a piece of luck that their machines are up to these limits. But from a cold-blooded basis of outright knowledge, any such statements today may turn out to be pure "bunk!"

Roger D. Prosser.[13] This paper covers the first really constructive piece of scientific investigation of a method of testing tungsten-carbide lathe tools, and developing equations showing the relations existing between cutting speed, feed, depth of cut, and tool life. It would certainly be interesting to see these tests carried further in a number of respects.

The size of the cemented-tungsten-carbide tip applied to the test tools has a very important bearing on the performance of the tools, and it would be very interesting to see the investigations extended to show a comparison of the performance between tools with various sizes of tips under the same cutting

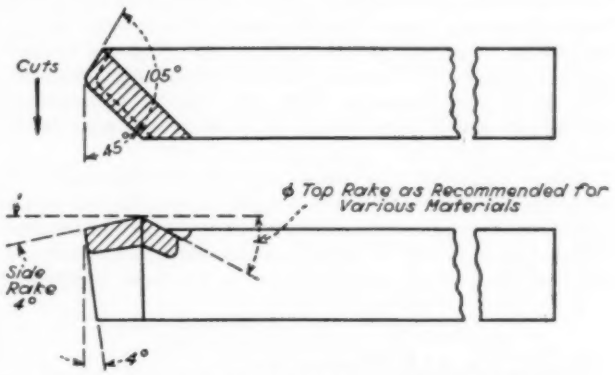


Fig. 13 Widia Tool, Krupp Shape for Heavy Work

conditions. The cost of cemented tungsten carbide necessitates its economical use, and such tests would indicate the minimum size of tip applicable for a given job.

Mr. Digges said that, with the copper brazed tools, it is necessary to remove the joint far enough away from the cutting edge so that it does not become dangerously hot during the operation. He also stated that premature failure in several tests resulted because of the rupture of this bond. Obviously, the tip of cemented tungsten carbide in this case was somewhat too small. A tip of sufficient size to carry away the heat would doubtless have overcome any difficulties in this respect.

In this connection, it has several times been stated that cemented-tungsten-carbide tools can be run with the cutting edges at a bright-red heat. Long experience and tests at the Krupp Works, where cemented tungsten carbide was originated, have shown that the best results are obtained when the speeds employed and size of tip are such that the heat is carried away and the cutting edge remains below a red color.

Mr. Digges stated that a small change in cutting speed causes a correspondingly large change in the tool life, so that the higher cutting speeds are obtained only at the expense of shorter tool life. In general, this is correct, but an interesting point is raised in that a higher cutting speed does not always result in a shorter tool life. In fact, when machining steel with cemented-tungsten-carbide tools, it is often possible to obtain satisfactory performance at a high speed, whereas with a slower speed the result is unsatisfactory. The writer has seen tests on machining

[13] Of Thomas Prosser & Son, New York, N. Y., American representatives of Fried. Krupp A. G., Essen, Germany.

electrode carbon when wear on the tool was actually less with a high speed than with a somewhat slower speed.

The statement is made by Mr. Digges that "if the curves are extrapolated to an extremely long tool life, then the curves will cross, and the high-speed-steel tools would show higher cutting speeds than the tungsten-carbide tools." This is of course theoretical, and it is quite doubtful whether this would be the result in actual practice. The writer believes, without having made investigations in this respect, that this result would not follow, but that for extremely long life the tungsten-carbide tools would still show a higher cutting speed than high-speed-steel tools.

The writer is in full agreement with the conclusions reached by Mr. Digges, and would especially call attention to his statements that, for a given area of cut, higher cutting speeds are obtained with deep cuts and fine feeds than with shallow cuts and coarse feeds; and also that high cutting speeds with relatively fine cuts are more favorable to successful application of tungsten-carbide tools then heavy cuts at slower speeds. The various manufacturers of cemented tungsten carbide have been trying to bring before the users of these tools the necessity for considering their limitations. Tungsten-carbide tools are not as strong as high-speed-steel tools, and therefore should be used with correspondingly lower chip pressures. This can best be accomplished through the use of high cutting speeds with somewhat lighter feeds than usual.

A few suggestions regarding practical considerations will doubtless be in order. It is felt that the form of the tool used in these tests, although a very good one, is not the best for tungsten carbide tools. In Fig. 13 is shown a tool which has been found, after exhaustive tests by Krupp, to be the most satisfactory

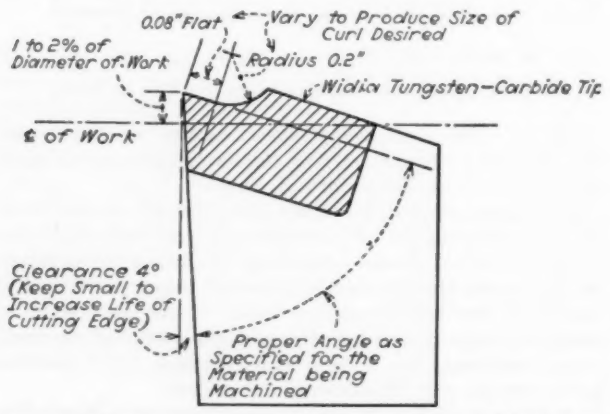


Fig. 14 Method of Grinding Chip Breaker in Widia Tool

for heavy roughing operations. The chip pressure on this form of tool is better distributed over the cutting edge than in the usual form of straight-side cutting tool. It also has other important advantages and is especially good for the machining of steel.

The clearance angle in the case of tungsten-carbide tools is of the utmost importance. It is noticed that Mr. Digges used tools with a clearance angle of 6 deg., and it would be very interesting if these tests were extended to show the relation of the clearance angle to the tool life. Clearance angles of 3 to 4 deg. have, in the majority of cases, resulted in greatly increased tool life, and some cases have been observed where a reduction of the clearance angle from 6 or 8 deg. down to 3 or 4 deg. has acutally doubled the life of the tools. Poor grinding is the cause of probably 80 per cent of all trouble experienced with tungsten-carbide tools, and it is of the utmost importance to observe carefully the grinding instructions of the manufacturers.

It is most important, when grinding a chip breaker on the top of the tool, not to weaken the cutting edge. Incorrect grinding of chip breakers is the cause of a large number of failures which have been encountered with tungsten-carbide tools. In Fig. 14 there is shown a satisfactory method of grinding a chip breaker, and it should be carefully noted that this is *not* accomplished by hollow-grinding the top of the tool; it is obtained by grinding a flat near the edge of the tool and parallel to the top surface of the tool. A small radius at the back of this flat produces very satisfactorily the proper form of chip, and the dimensions of the curl can be regulated by the width of the flat and the dimension of the radius. With this method the angle of the cutting edge can be made correct for the material being machined, and by this means the tool is not weakened, as in the case of hollow grinding.

Fig. 15 shows how hollow-grinding and the grinding of too great a clearance greatly weakens the tool.

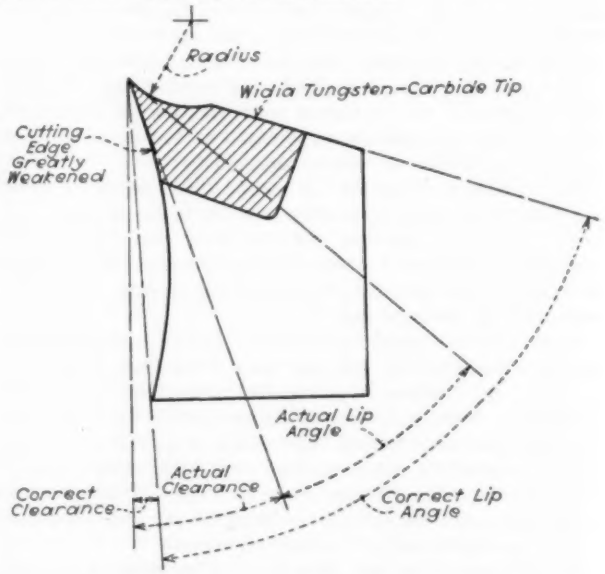


Fig. 15 Incorrect Grinding of Chip Breaker and Clearance in Widia Tool

It should be carefully borne in mind that the comparisons made by Mr. Digges between cemented-tungsten-carbide tools and high-speed-steel tools are applicable only to the grade of tungsten carbide used by him, and which contained about 13 per cent cobalt. With a harder grade, considerable higher cutting speeds would be obtained.

Mr. Digges points out that when the tool starts to become dull, the chips become shorter and shorter, with more and more curl, until they become very short indeed, rapidly breaking off from the work instead of coming off in clean-cut ribbons. It is most important for all users of tungsten-carbide tools when machining steel to note this point and to carefully instruct their men to remove tools from the machine for resharpening as soon as this condition begins to become apparent. Many failures of tungsten-carbide tools are due to allowing the tools to run after becoming dull, resulting in increased chip pressures and often bad breakages of the tools. This condition could be avoided by the observance of the form of chips and removal of the tool in time.

The investigations of Mr. Digges should be of the greatest value to all users of tungsten-carbide tools, and the writer wishes to compliment him on this contribution to the art of cutting metals.

Author's Closure

The author agrees fully with Mr. Williams that rigidity is essential for the maximum cutting efficiency with cemented-tungsten-carbide tools. However, this tool material can be and is being used to an advantage in a number of shops with the present machine-shop equipment. There is no doubt that in a number of cases a change in machine design is necessary in order to utilize the full cutting capacity of the new material.

It is very gratifying to have such close agreement between the conclusions made from the results of these experiments and those from actual shop practice as found by Mr. Prosser and his associates.

The author certainly appreciates the interesting discussions by Mr. Williams, Mr. DuBrul, and Mr. Prosser and hopes that additional results will be available for discussion at some future time.

MSP-52-14

Mechanical Lapping

By SYDNEY PLAYER,[1] WORCESTER, MASS.

IT IS A well-known principle of machine operation that ordinarily a machine can produce nothing more accurate than itself. However, by the use of modern lapping machines it is possible to produce work that is far more accurate than the machine being used.

The art of lapping is not new; it is so old it is impossible to determine its origin. With the ever-increasing demand for greater accuracy in mass production, particularly in the automotive industry, there arose an urgent need for some practical method of obtaining this accuracy easily, uniformly, and economically. It was common knowledge many years ago that the finest and most accurate surfaces produced on hardened steel were produced by the old method known to the trade as hand-lapping. This method was very slow and expensive, and could be performed only by the highest class of toolmaker. Hence it was used only when absolutely necessary. As a matter of fact, it is still used today in toolrooms where gages are made singly or where shapes of work are such that to lap by machine is not possible.

During the war there was developed by the Bureau of Standards, Washington, D. C., a method of mechanically lapping flat surfaces. This method, it is believed, is today known as the Hoke method. At the conclusion of the war it was adopted by the Pratt & Whitney Company, which, with the assistance of Major Hoke, developed and built what the author believes to be the first mechanical-lapping machines made in this country. However, these machines were for lapping flat surfaces only, and were used for lapping the Hoke size blocks, with which no doubt all are familiar. These machines, it is believed, are still in use and operating satisfactorily on this same work.

Early in 1922 the Bethel Player Company designed and marketed a cylindrical lapping machine, primarily for the production lapping of piston pins. This machine was a crude affair compared with the present-day machines. The production was small and the cost excessive, but the advantages gained far offset those items. Progress in the development of further machines naturally followed.

The year 1927 witnessed the development of new lines of improved lapping machines, both for the lapping of high precision work and for mass production where accuracy as well as rapid production is demanded.

A brief description of the machines at this point will no doubt help one to grasp the rapid strides the art has made.

Since this paper is devoted entirely to cylindrical and flat lapping, it will be confined to the description of machines for that purpose. There are two types of machines built, as follows:

(1) Vertical lapping machines for flat work (or cylindrical work) employing cast-iron plates for laps
(2) Vertical lapping machines employing a pair of abrasive lapping wheels.

Vertical Lapping Machine for Flat or Cylindrical Work

This machine is used primarily for precision cylindrical lapping, the work best suited being plug gages and other cylinders which require extremely close tolerances of accuracy. The machine has been designed along modern lines.

The lapping disks are made from a soft, close-grained cast iron. The lower lap revolves at a speed of 60 r.p.m. running counter-clockwise. The upper lap is stationary and free to float to find its own level, when brought in contact with a cage full of work to be lapped.

The lower lap is mounted on a tubular spindle driven by a hardened steel worm and bronze worm wheel, having a ratio of 10 to 1. Through this tubular spindle is a shaft running in bronze bushings and driven by a train of gears from the tubular spindle. This is called the "break-up shaft," for on its upper end is mounted a head with an adjustable slide carrying a drive pin. This drive pin is eccentric with the spindle an amount suitable to give sufficient movement to the workholder.

The workholder has a bushing in its center and is free to turn upon the eccentric drive pin. When the lower lap rotates, the work, being between the stationary and rotating lap, acts as a set of roller or ball bearings, carrying the workholder or cage around the eccentric drive pin at a speed of approximately one-half that of the rotating lap. The eccentric drive pin is driven in the same direction, but at a different rate, and the combination of movements due to the rotation of the workholder by a moving guide pin gives an ever-changing position of the work relative to the face of laps. This is what is meant by "break-up."

The vertical lapping machine, for lapping flat surfaces, is similar to the machine just described, with the exception of the workholder drive mechanism. It is used for precision flat lapping, such as gage blocks, etc.

The mechanism used for driving the workholder, or cage, is arranged to impart a motion to the work similar to that used by a toolmaker in hand-lapping. The lower lap again rotates on the tubular spindle by means of a worm and worm gear, the same ratio and speed being used.

Through the tubular spindle is mounted a stationary shaft, on the upper end of which is fastened a stationary gear. There is a head mounted, free to rotate upon the stationary spindle, and on this head are three vertical studs. On these three studs are the three workholder drive pinions in mesh with the stationary central gear; enveloping the three spider-drive pinions is a ring gear which is mounted on and driven by the tubular lap spindle. On the head of each spider-drive pinion a vertical drive stud eccentric with the pinion makes contact with a set of three bushings in the workholder. Upon rotation of the lap the ring gear imparts motion to the workholder drive pinions, these being mounted on a "sun and planet" train of gears. With the central gear stationary, the desired motion is given to the work. The ratio of the gears is chosen so that there is the same relative movement of the work with both stationary and rotating laps.

The workholder, or cage, used on these machines varies considerably from the simplest piece of sheet metal perforated with holes to the most complicated fixture. Its function is to hold the work in the proper relationship to the face of the laps and to impart the motion of the workholder drive studs previously referred to. The fixture most commonly used is what is known as a "leg spider," which consists essentially of a circular plate of aluminum, the edge or periphery of which is drilled and reamed with taper holes. These holes are not drilled radially, but are tangent to a circle approximately 3 in. in diameter drawn con-

[1] Norton Company.

Presented at a meeting of the Metropolitan Section, A.S.M.E., at Newark, N. J., March 20, 1930.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

centric with the center of the aluminum plate. In each hole is driven a spindle; this spindle is parallel and is about $^1/_{16}$ in. smaller in diameter than the hole in the cylinder to be lapped.

The cylinders to be lapped are assembled on these spindles on the workholder. They are free to revolve and have approximately $^1/_8$-in. end play. Outside the ends of the cylinders to be lapped and resting on four spindles which are longer than the rest, a ring is dropped retaining the cylinders on their respective spindles. Thrust plates are provided in the ring for each cylinder to rub against. This type of workholder lends itself to rapid loading and unloading, but two are usually provided for each machine so that there is no lost time in the machine when in operation. This type of workholder is lifted on and off the machine completely loaded.

A simple type of workholder, such as is used for flat work, consists of a circular steel plate suitably bushed for the drive studs, and arranged with holes or perforations to suit the work to be lapped. This type of workholder stays on the machine and is adjusted so that it touches neither lap, and the work is placed in the perforations while the holder is in position in the machine. These pieces are easy to load and unload; therefore, little time is wasted on this operation.

It is essential in all lapping operations that the laps be kept in good condition, both as to surface and form. The lap surfaces must be carefully prepared before commencing the lapping operation. The real secret of machine lapping is in having the lap surfaces in true plane. For very precise work the laps are hand-scraped from planing to a good surface plate. Three laps are taken and worked together, using as an abrasive nothing coarser than can be used for the lapping operation. For commerical work the scraping operation may be eliminated and a fast-cutting artificial abrasive, such as silicon carbide, used.

New laps are prepared by the following method before assembling on the lapping machine:

The working together is performed on an upright drill press, one lap being fastened to the table of drill press, the other lap resting on the top of it, the surfaces being prepared coming together with a film of abrasive and oil between them. From the spindle of the drill press extends a short throw crank. The crankpin of this crank is allowed to enter a driving hole in the center of the upper lap, this same upper lap being free to rotate and float freely about the crankpin. The drill press being set in slow motion, the upper lap is made to move in a circular path eccentric with the lower lap. This motion also makes the upper lap rotate slowly about its own axis, and the combination of these two motions has the effect of making the lapping faces of the pair of laps match each other.

The laps are made in the form of a heavy ring with the hole in the center greater than half the outside diameter. The thickness is usually 3 to 4 in. to prevent any distortion while in use. To obtain the true plane necessary these laps are taken, as previously mentioned, and by numbering them 1, 2, and 3 they are worked together in the following manner:

One with two, one with three, two with three, and so forth, as in the production of master surface plates. Having generated these true lapping surfaces, any subsequent dressing operation may be performed without removing them from the lapping machine, unless their form has been unduly destroyed.

This dressing operation is performed by releasing the overarm supporting the upper lap, allowing the upper lap to rest upon the lower with suitable abrasive, or lubricant, between the faces, and while the lower lap is rotated the upper one is moved back and forth a short distance by hand across the surface of the lower lap.

All is now ready to commence the lapping operation proper. Assume a number of steel cylinders 3 in. long, 1 in. in diameter, with a $^1/_2$-in. hole through them. The finished size is to be 1 in. plus 0.0001 in., minus 0.0001 in. The cylinders are finished ground to a limit of from plus 0.0002 in. to plus 0.0004 in. The finish of the grinding is not material, just as long as the diameters are within the foregoing limits. They are then loaded on the workholder and placed between the lapping plates.

A fine abrasive has been prepared, consisting of dust fines, aluminious oxide abrasives, mixed with kerosene and lard oil. The abrasive is then applied with a brush in small amounts and the machine is started. Between 30 and 40 cylinders are lapped at once. After running the machine for a few minutes, one is taken off and measured. Having been careful to take the time necessary to bring the first load down to size by giving all subsequent loads the same amount of time, and providing the grinding is between the limits specified above, load after load will be the same size, or easily within the limit of standard and plus 0.0001 in. The same procedure is followed for the lapping of flat disks, within these limits.

The average production on cylinders, removing the amount of stock specified, is about 60 to 70 per hour. A good commercial finish results.

For precision lapping to very close tolerances, two operations are required. For example, it will be assumed that there are being lapped 30 plug gages of a size 0.875 in. in diameter to limits of plus or minus 0.00002 in. To lap to this close tolerance, it is a better and quicker operation if the grinding is held to a closer limit than the commerical limit specified. Very good results have been obtained from a grinding limit of plus 0.00015 in. to plus 0.0003 in. In this case the laps used for both roughing and finishing must be prepared by hand scraping. Great care must be used in the dressing of these laps. In the case of roughing, the same abrasive is used to dress as that used to lap.

The author has found M-304 American Optical Emery a good rougher and fairly fast in its cutting action. This abrasive leaves a good surface for finishing.

The plug gages are lapped to within 0.00005 in. of finished size in this roughing operation. During the course of this operation, the work is transposed or rearranged in the workholder, usually by taking every alternate piece and placing it diametrically opposite. This means moving one-half the number of gages each time. By transposing, as just described, it will be readily seen that the larger diameters can be commingled with the smaller. By doing this three times during the course of the operation, one is assured of true parallelism and uniformity.

Having reached the stage for finishing, the gages are carefully washed without disturbing and placed in the finishing machine. The laps on the finishing machine have been hand-scraped, and then worked together with "levigated alumina" or "jewelers' rouge" until the surfaces of the laps are mirror finished. The operation is then continued without any further application of abrasive; a small amount of fine lubricant is used, however, to prevent the surfaces from drying. By continuing this method perfect mirror-like surfaces can be obtained, providing the material is suitably chosen and properly heat-treated.

For the complete lapping of these 30 gages to the foregoing limits, the time taken would be from two to three hours, the roughing only taking 30 min. Exactly the same procedure is followed for the lapping of precision size blocks.

Early in 1928 new types of production lapping machines were developed. These machines differ from the machines described previously in that they are very much heavier and abrasive bonded wheels are used for laps. Differing also from the previous machines, both abrasive wheels revolve in different directions.

For cylindrical lapping the top wheel runs 99 r.p.m., the bottom wheel 113 r.p.m. For flat work the same speed is used

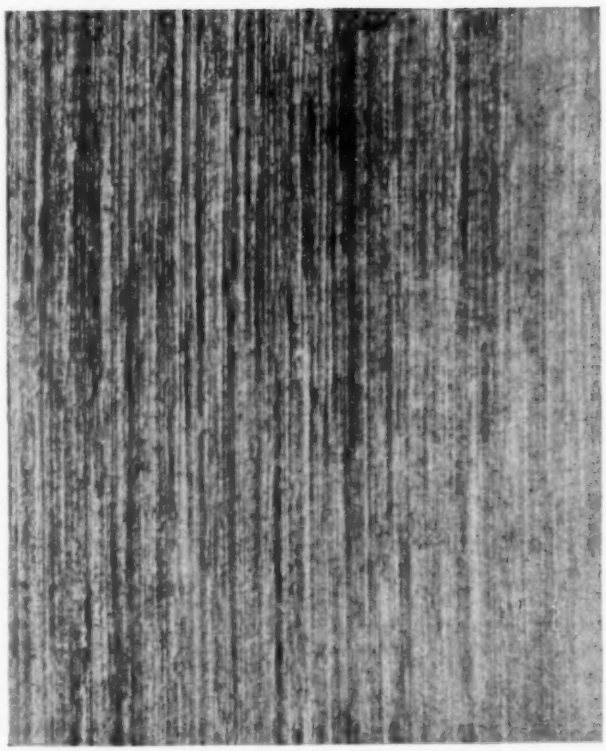


FIG. 1

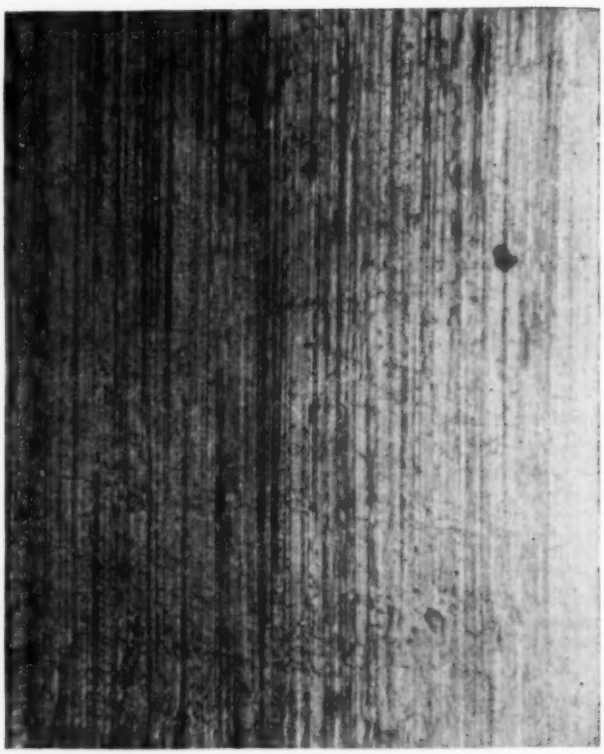


FIG. 2



FIG. 3



FIG. 4

for the bottom wheel, 113 r.p.m., but a little different speed is used on the top, 103 r.p.m. The upper wheel runs clockwise, and the lower wheel runs counter-clockwise. The reason on the cylindrical machine for the difference in speeds of the lapping wheels is to make the cage, or workholder, rotate about the eccentric drive pin, the combination movement thus given im-

parting what is known as a "break-up" to the work, relative to the lapping face of the wheel.

The "break-up" mechansim in both these machines is identically the same and needs no further description. The workholder, or cage, is the same.

For the dressing of the wheels a diamond dresser is provided, and both wheels can be dressed in true plane. The wheels preferably used are 24 in. in diameter by 3 in. thick, with a 14-in. hole. This gives the wheel a 5-in. face and enables one to lap work to that length.

The wheel problem presented great difficulty. However, we have succeeded in making wheels commercially, both for the rapid removal of stock and for the fine finish which is necessary for a lapped surface.

For rough lapping silicon-carbide abrasive or vitrified aluminum-oxide abrasive lapping wheels are used. For finishing, a very fine flour grain, silicon carbide, and shellac-bonded wheels are used with good results. Lubricant is pumped to the work and wheels from a large tank placed beside the machine, and consists of soap and water, lux being most commonly used.

Production on these machines is astounding, 500 piston pins per hour being easily maintained day after day, to limits of 0.0001 in. for straightness and roundness; stock removal for roughing, 0.0002 to 0.0004 in; for finishing, nothing to 0.0002 in. over high limit of finished piece.

Another big advantage gained in the use of bonded abrasive wheels is that no cleaning operation is necessary, as in the case where loose abrasive is employed.

This type of machine can also be used successfully in the lapping of soft metals, such as piston rings. By using these bonded abrasive wheels for laps it is claimed by engineers that no charging takes place, as is the case when lapping soft materials with cast-iron laps and loose abrasive. Several of these machines are in operation lapping the wristpins of airplane motors. These pins are comparatively soft, and when lapped by this method a bright mirror surface results. When using loose abrasive and cast-iron laps the finish is dull gray. While bonded abrasive wheels are used, this operation must not be confused with grinding as it is known today.

The face of the wheel is used and not the periphery. The results show no feed lines, no traverse marks, no corkscrew effect, but lines that are criss-crossed giving that velvety "matt surface" which shows the effect of genuine lapping. A high polish can be obtained by grinding machines by the use of fine-grained wheels and slow feeds, but upon close examination the grain marks run circumferentially and have ridges very much like fine threads.

A machine-lapped surface coming in contact with another moving part reduces friction to a minimum. It provides a more thorough and uniformly efficient distribution of the oil film surrounding it. Consequently, machine-lapped working parts, particularly those under great stress, will wear longer without reduction in size and there will be less risk of seizure, less noise, and longer life.

In the same way such parts as plug gages and gage blocks have a considerably longer life when lapped. This has been further substantiated by statistics compiled by several manufacturers who have made a study of gage life.

When machine-lapped parts are used in mass production, it is seldom necessary to have selective assembly. By this is meant that, with the very close limits to which machine lapping is held, it is not necessary to separate into groups of oversize or under limits, so that they may be chosen to fit a corresponding part that may be over or under size in itself, because of the wider tolerances of other methods of production.

Machine lapping eliminates all, or a great deal, of this selection of parts and its corresponding loss of production time.

Having described the machine and its operation, there will now be given some information concerning the cost of the operation and the almost unbelievable advantage of machine lapping over any other method of finishing a surface of hardened steel.

The author can do no better than quote from a paper[2] by L. M. McPharlin, supervisor of gages and inspection methods, Studebaker Corporation of America. Mr. McPharlin's paper states:

> The finish is most important and should be as smooth and uniform as it is possible to produce. We have found in our tests that the quality of finish governs to a greater extent than any other factor the wear life of plug gages; and when factors such as the steel, its treatment, and hardness are equal, finish is the deciding factor in the wear life.
>
> The experiments described were in progress for two and a half years and were necessarily slow in terminating, as the gages were used on production inspection and were carefully watched to avoid errors of any nature.

A comparison of accumulated wear of hand-lapped and mechanically lapped plug gages follows:

Both gages plugged 6000 holes; the hand-lapped gage lost 0.00065 in. end, 0.00028 in. center, and 0.00012 in. back. The mechanically lapped gage lost in size 0.0002 in. end, 0.00002 in. center, nothing back. The two gages differed only in surface finish. They were both of the same size, made of the same kind of steel, hardened to 87 scleroscope, and were the same material. The mechanically lapped surface showed 454 per cent more life then the hand-lapped surface.

This paper by Mr. McPharlin is a very interesting one and is well worth reading.

Further data have been obtained on lapping in massed production form. One of the large automobile plants is using 35 centerless grinding machines for grinding wristpins, leaving 0.0003 in. for lapping on vertical lapping machines employing abrasive lapping wheels. Four machines are used for rough lapping and four for finishing. These eight machines lap around 10,000 pins in 19 hours, or better than 500 pins per hour.

To illustrate this, the series of microphotographs of wristpins herewith show the surfaces magnified 300 times. The pins shown are the same in all photographs.

Fig. 1 shows a good commercial centerless ground finish.

Fig. 2 shows what is called a centerless lapped finish.

Fig. 3 shows a rough lapping operation performed on a vertical lapping machine after the operation of centerless lapping.

Fig. 4 shows a finish-lapped pin done on a vertical lapping machine following the rough lapping. It is not necessary to comment on the difference in surfaces shown; the finish surface mechanically lapped on a vertical lapping machine being far superior to the one finished on a centerless grinder and the one described and shown as centerless lapped. The one described as centerless lapping appears good to the eye, is highly polished, but underneath the polished surface all the evidence of the grinding wheel may be found, and after pushing through a bushing the high spots will be noted. Experience has shown that this pin will lose its size rapidly until all the high spots are rubbed down to make what is known as a "worn surface." The surface from a vertical lapping machine needs no further running in, the high spots being lapped to a matt finish.

In the author's early experience a test was made at one of the large automobile factories, running an engine several hours with ground pins versus lapped ones. After several hours of running the engines were dismantled and the pins were measured. The ground pins had lost in size 0.0003 in., and the lapped pins showed no measurable difference in size.

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[2] *American Machinist*, May 12, 1927.

MSP-52-15

Tungsten-Carbide Cutting Materials

Progress Report No. 2[1] of Subcommittee on Tungsten-Carbide Cutting Materials of the A.S.M.E. Special Research Committee on the Cutting of Metals

By FRANK C. SPENCER,[2] KEARNY, N. J.



WITH THE assistance of the National Machine Tool Builders' Association, this subcommittee has sent out letters and questionnaires to over six hundred users and builders of machine tools requesting certain specific information based on their experiences with the use of tungsten carbide as a cutting material. It was thought that the analysis of a large amount of data obtained in this manner would bring to light such deficiencies as might exist in the tools and in the machines which, if corrected, would make it possible to obtain the maximum advantage from the use of this material. Copies of the letter and questionnaire are included as a part of this report.

About seventy-five concerns had replied at the time this report was prepared, of which about fifty furnished data on most of the items covered by the questionnaire. The others were making tests but had no information available, or had not used tungsten carbide at all. Replies are being received daily, and it is hoped that sufficient information will be obtained to warrant the preparation of a more complete report later. The following is a digest of about fifty replies presenting experiences with the use of tungsten-carbide tools and comments of users bearing upon the design of machine tools.

A—Extent of Application

The returns show that a relatively small average number of machining operations are now being regularly performed using tungsten-carbide tools, although in two companies the number of applications is over 500 in each. Probably a better indication of the extent of application is the low percentage of the number of tungsten-carbide tools to the total number of tools available. This percentage is considerably less than one per cent; but there are, however, several notable exceptions—one machine-tool builder reports 5 per cent, one 15 per cent, and another 25 per cent. One company is using tungsten-carbide tools for 75 per cent of all cast-iron turning.

While the total volume of production now being obtained with the use of tungsten-carbide tools is still relatively small, the replies indicate that practically all of the companies reporting have definite programs planned which contemplate the more extensive use of tungsten carbide, provided that "tests which are now being conducted prove to be satisfactory."

One company is planning to equip 1000 machines with tungsten-carbide tools for the general machining of metals, and another is conducting a test which, if it "shows that a saving can be effected, plans to use them exclusively on all cast-iron, semi-steel, bronze, and brass machining," with the possibility of extending the application for machining 1000 different parts.

B—Kind of Material Cut

Experiences indicate that tungsten carbide is superior to tool or high-speed steel as a cutting material on all non-ferrous metals regardless of the hardness or the condition of the surface, especially for roughing cuts on production jobs. Not all are agreed, however, that finishing can be done as satisfactorily as with high-carbon- or high-speed-steel tools, because "tungsten carbide is comparatively weak and brittle," and "will not hold a fine, keen edge."

Cast iron submits readily to the tungsten-carbide tools even when the surface has a hard sandy scale. One company reports, "We have to cut through chaplets and welds where blowholes have been acetylene welded. Tungsten carbide does not seem to fail in cutting through these defects." Others report similar experiences.

A difference of opinion exists as to the advantage of using tungsten-carbide tools in machining steel. Several report failures in attempts to improve on high-speed-steel performance, while others are enthusiastic about the use of tungsten carbide for machining steel and report having readily machined alloy steels which could not be machined economically with high-speed steel. One company reports machining a hand-forged nickel-chromium steel airplane propeller shaft. It is stated: "It was extremely tough and irregular in shape, necessitating in frequent instances materially heavier cuts on one side than on the other. Scale conditions and hard spots were particularly difficult." The shaft was turned on a Gisholt turret lathe about 10 years old but in good condition. "The job was successfully completed using tungsten-carbide tools—as we found it absolutely impossible to finish the machining of the parts using high-speed-steel tools without first annealing the forgings, and then only with great difficulty."

C—Machine Equipment Used

Machines on which tungsten-carbide tools have been used successfully on regular production include practically all standard types of metal-cutting machines, except milling and drilling machines which, replies indicate, have been equipped with tungsten-carbide tools for use principally on an experimental basis.

The machines on which tests were made or on which regular operations were being performed in most cases were reported in good condition. Two reported as follows: "Condition varies from good to poor, much more satisfactory results being obtained from machines in good condition." An electric company, in

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[1] This report was presented at the Machine Shop Practice Session of the A.S.M.E. Semi-Annual Meeting in Detroit, Mich., June 9, 1930.

[2] Assistant Superintendent, Manufacturing Development, Western Electric Co. Mem. A.S.M.E. Mr. Spencer was employed as a draftsman in the Ordnance Department at Washington during 1902 and 1903, and in 1904 was appointed chief draftsman at the Springfield Armory, Springfield, Mass. In 1918 he held the position of superintendent of the Browning Gun Department at the Colt's Patent Fire Arms Manufacturing Company at Hartford, Conn., but during most of the time since 1906 he has been employed by the Western Electric Company in various capacities, starting as machine designer at the Chicago plant. In 1923 he was placed in charge of the machine-design division at Hawthorne and in 1925 was appointed assistant superintendent in charge of manufacturing development. During the last couple of years he has been engaged principally in the procurement of machine equipment for the new plants of the Western Electric Company.

referring to its equipment, stated, "Generally one will find the equipment in fair condition and about 5 to 10 years old. Tungsten carbide can be used advantageously on machines of this age provided the proper selection of the tool is made."

D—Tungsten-Carbide Tools Used

Practically all of the tools used by the companies reporting were lathe- or planer-type tools in a large variety of shapes and sizes, some having shanks as large as 2 in. × 2½ in. Tips in most cases were simply brazed, though a few were inserted, and in one or two cases they were dovetailed and brazed. The rake and clearance angles in most cases were those recommended by the suppliers, but in some instances customers found modifications of these angles desirable on certain kinds of work. This subject is sufficiently important to warrant further consideration, and it will probably constitute one of the Commitee's future activities.

E—Grinding of Tungsten-Carbide Tools

As reported above, lathe and planer tools constituted a large majority of the tungsten-carbide tools reported upon, and the grinding was done mostly by hand. Eight out of thirty companies reported using cutter-grinder machines also. A few of the companies have the grinding done by the suppliers One company reports grinding "not essentially different from standard tool-dressing methods;" another, "Tools were ground in our tool room by one man, who was instructed as to proper methods."

A gear company cutting cast iron, brass, and bronze castings reported that the time consumed in grinding is from one to three hours, according to the condition of the tool. Another stated that the time required is twice that for grinding high-speed-steel tools, while another, machining bronze, reports three to five minutes as the average time required.

A company machining "nearly all commonly used materials" reported that "considerable time was spent in sharpening tools, and we found it difficult to maintain a keen edge for any length of time." Another shop doing very heavy work stated that "after original grinding, only a few minutes each day is required for occasionally touching up the cutting edge." A company machining aluminum alloys reports the time for grinding is negligible, and another reports the time consumed about 5 times that of high-speed-steel grinding.

Apparently the practice of grinding tungsten-carbide tools differs as greatly as the grinding of tool-steel and high-speed-steel tools. The importance of maintaining the correct rake and clearance angles on tools used for production work which can only be accomplished by machine grinding, seems to be generally disregarded. The subject of small-tool grinding warrants further investigation.

F—Method of Lapping

Of 40 companies, 11 reported the use of tungsten-carbide tools lapped or stoned. The lapping has been done mostly by hand, using a cast-iron lap, though in a few cases disk lapping machines are used, silicon carbide or diamond dust with oil being used as an abrasive. The advantage of lapping tungsten-carbide tools is questionable.

G—Cutting Speeds Used in Feet per Minute as Compared With Cutting Speeds of Tools Previously Used

The increases in cutting speeds using tungsten-carbide tools in cutting cast iron and non-ferrous metals have been from two to three times the cutting speeds using high-speed-steel tools. Many are using the highest speed that the machines will permit. One report stated relative to cutting bronze, "We have made several tests of cutting speeds and have got as high as 400 ft. per min., but could not maintain this due to the construction of our machine tools." Another reported: "In a few cases where we originally tried to get full speed and feed capacity of the tool, the strain on and chatter of the machines was so great that we had to cut the speed down, and we are now only increasing speeds gradually as operators get familiar with the tool possibilities."

H—Feeds Used in Inches per Revolution or Stroke as Compared With Feeds on Tools Previously Used. I—Depth of Cut in Inches

The general practice seems to be to use about the same feeds and depth of cut in cutting with tungsten-carbide tools as with high-speed-steel tools. No radical differences have been reported. A tendency is indicated, however, toward lighter feeds, with much higher cutting speeds than are used with steel tools.

J—Economies in Percentage of Increased Output as Compared With High-Speed Steel and Stellite

Some remarkable increases in outputs per grind using tungsten-carbide tools for machining cast iron and non-ferrous metals have been reported, as compared with high-speed-steel tools. These increases appear even more remarkable when we consider that the cutting speeds used as already noted were in most cases from two to three times former speeds using high-speed-steel tools.

A company machining silicon-aluminum alloys reports that with the use of tungsten-carbide tools they obtained 4500 to 35,000 pieces per grind, whereas with the use of high-speed-steel tools they obtained 100 to 1800 pieces per grind. An airplane company in turning aluminum bronze obtained 2000 pieces per grind using tungsten carbide, against 60 pieces per grind using high-speed steel, and in boring aluminum-alloy crankcases having 8 bearings each, 50 to 75 crankcases per grind using tungsten carbide, against one using high-speed steel. Another airplane company stated that they could not report on the output of some of their tungsten-carbide tools because of the fact that the set-ups have not been disturbed since the tools were first put to work more than six months ago.

A company machining cast iron reported 1500 pieces per grind using tungsten carbide as against 100 using high-speed steel. They also reported that in grinding they do not remove more than 0.003 in. to 0.005 in. from the tungsten-carbide tool, whereas up to 1/32 in. is ground away each time the high-speed-steel tool or stellite tool is ground. Another company machining cast iron reports the number of pieces per grind using tungsten carbide is 1500 per cent over the number using high-speed steel, and the increase in the number of grinds in the life of the tool "due to the small amount removed in grinding would be about 200 per cent."

A valve company machining non-ferrous metals reported as follows: "As compared with high-speed steel, one particular job shows an increase of approximately 2400 per cent in pieces per grind and an increase of approximately 560 per cent in the number of grinds per tool. On another operation where tungsten-carbide tools replaced high-speed steel, the number of pieces per grind increased something like 1600 per cent."

Practically no information was furnished relative to a comparison of tungsten-carbide tools with stellite tools with respect to the output per grind.

Longer runs without the necessity of shutting down for tool grinding result in an appreciable increase in machining production efficiency, without the necessity for spectacular increases in cutting speeds. Large economies are effected with the use of tungsten carbide on such operations, even when used on equipment that was not designed for the severe service tungsten carbide will withstand.

Considering the gain in production resulting from long, uninterrupted runs combined with the gain resulting from the high

cutting speeds obtainable with this material, the possibilities of cost reduction are considerable.

K—Failures

A few companies reported no failures whatever, although most of the companies including those which have been able to effect satisfactory savings using tungsten-carbide tools have had several discouraging experiences—some due to unsatisfactory tools, some to machine deficiencies, and some no doubt to unfamiliarity with the technique involved in the use of the material.

With respect to tool troubles, one large company stated: "We have had set-ups which gave us considerable trouble, and which finally worked out only after a new set of tools was installed by changing suppliers. We believe that tungsten carbide is very inconsistent in hardness and grain structure, and that the tipping is not always satisfactory, which generally causes failure of a set-up." Another stated: "Our failures have been under heavy cuts which caused the shank of the tool directly under the cutting edge of the tungsten-carbide bit to compress and mushroom out, causing the tip to break due to improper support."

One large company's report summed up the statements of several: "Have had the usual failures experienced by others, such as those due to tools having too great overhang, to making intermittent cuts, to operator stopping machines and starting again with feed on, to operator running machine in reverse accidentally, to not exercising care when tool leaves the work, and when blowholes are encountered."

Quoting from reports of other companies: (1) "We could only increase speed a little before we reached the maximum speed of machine, and when we attempted to increase the feed, the tips came off." (2) "The only failures we have had were when the tool had to be stopped in the cut. Sudden shocks break tungsten-carbide tools." (3) "Set-up called for three roughing tools at one time. It was necessary to remove one tool for lack of power after the belt and clutch were tightened as much as possible without injury to the machine." (4) "On the full-automatic lathe, the tools were used in conjunction with a follow rest and the work was driven by means of serrated dogs. Any slight slipping of the work or misalignment of it while being inserted or ejected from between centers chipped the cutting edge, and it seemed almost impossible to get a full run from a tool." (5) "The machining of malleable-iron and brass wedge gate-valve disks has been unsuccessful owing to considerable vibration when running at the proper speed. Although the floor under the machine was strengthened and an entirely new machine installed, considerable vibration still existed and resulted in chatter." (6) "Tried tungsten-carbide tools and found that the first requirement of their successful use is rigidity of the machine tool. Since we have practically no machines in our plant rigid enough for the use of these tools, we abandoned further experiments."

A condition reported by two companies regarding the wear of the front face of the tool, thus reducing the clearance angle, is stated by one of them as follows: "Had no particular success on tough steels. There seemed to be a pressure on the nose of the tool which resulted in an abrasive action which rapidly wore away the front clearance."

Another unsatisfactory condition reported by three companies was the wearing of a groove on the top of the tool directly back of the cutting edge. One of the companies stated that this occurred when machining nickel-chromium-steel forgings and caused the cutting edge to break. This difficulty was obviated by grinding a groove at the point where it wore, thus reducing the compression of the chip as it was being cut from the work, and consequently reducing its pressure on the top of the tool.

L—Suggestion for Design Changes of Machinery to Make Possible the Most Efficient Use of Tungsten-Carbide Tools

Practically all of the experiences reported indicate that this material possesses possibilities for the improvement of machining practices far beyond those already attained, provided further improvement is made in the material and in the tools and machines to withstand the more severe service to which they will be subjected. There is still much to be done, especially in the design of machines, and a consideration of some of the suggestions which have been submitted for their improvement would not be amiss. The suggestions are as follows:

1 Utmost rigidity of the frame, driving shaft and spindle, tail stocks, or other members subject to strain is essential in order that deflections shall be extremely small.

2 Large-capacity ball bearings, preferably preloaded, or adjustable roller bearings of precision quality, should be used for spindles to withstand heavy loads and to eliminate bearing clearances or reduce them to a minimum.

3 Considerably higher speeds are obviously necessary.

4 Greater power should be provided, with a large allowance for overload so that machine will not stall when cutting.

5 It is important that feeding mechanisms be designed to eliminate jumping due to the building up and sudden release of pressure on tools.

6 Tool holders should be heavier and designed to eliminate the overhang of tools, and the method of clamping tools in holders should be improved to insure rigidity.

7 Better provision should be made for handling chips and for protecting operators from flying chips.

M—Any Additional Information That Is Available, Such as the Attitude of Labor With Respect to This Material, the Difficulty of Training Operators in the Use of It, Difficulty of Tipping Tools, and the Like, Would Be of Value

The replies received contain much valuable information and many terse comments pertinent to the subject of tungsten-carbide applications, and this report would be incomplete without the inclusion of some of them. The following are typical:

1 "After the operators become familiar with the possibilities of tungsten-carbide tools, they are reluctant to go back again to high-speed steel."

2 "We have been conducting a lot of tests, some successful and some not. We started out using just one or two tools on different machines, obtaining various results. We finally completely equipped one 24-in. Bullard turret machine with a set of 13 tools which covered practically all of the work which we were doing on this type of machine. This was at a cost of $652 as against a cost of $43 for high-speed tools of the same size and number. We have kept comparative costs as against high-speed steel, and find that our savings average approximately 31 per cent in time over that of high-speed steel."

3 "Tungsten-carbide tools have not progressed beyond experimental stages, though we have been working with the material ever since its introduction. We have not found it satisfactory as a cutting medium in our production work, where we are called upon to machine high-carbon chrome-steel forgings of an analysis similar to S.A.E. 52,100 annealed to a Brinell hardness of 170. In all trials of tungsten-carbide tools on this material it has proved less satisfactory than cobalt high-speed steels.

"We have found tungsten-carbide tools exceedingly satisfactory on cast iron, where we have been able to take very increased depths of cut at higher cutting speeds.

"We note an interesting condition in the use of tungsten-carbide tools on either high-carbon chrome or low-carbon steels:

namely, that if we introduced the tool into the work carefully, a continuous cut could be taken at high surface speed and corresponding coarse feed, without any detriment to the tool so long as the tool was not removed from the cut; but when the tool was removed, a small piece of the cutting edge remained in the work. This was demonstrated any number of times, and so far we have found no way of overcoming this difficulty.

"In general, we believe that standard machines made within the last three or four years are sufficiently powerful and have the necessary speed range to use tungsten carbide on work to which it is adapted. We have every confidence in the possibility for increased production and savings in the cost of machine operations by the careful application of this material."

4 "Generally speaking, we have found it impractical to adopt tungsten carbide as a cutting material for general use in our shop. While greatly increased speeds and feeds are possible on certain jobs, the overall saving on most of our work does not justify the high cost and frequent breakage of the tools. The reason for this condition is that the actual cutting time is not a very large part of the total time, because we subdivide cuts wherever possible and because our quantities are not very large. We also have to machine parts which are too frail to stand any more speed or feed than is obtainable with a high-speed-steel tool.

On the other hand, we have found tungsten carbide to be very useful in cases where we have had to machine hard or abrasive materials such as chilled cast iron, hardened steel, very hard bronze, sandy steel castings, or other materials which high-speed-steel tools would not cut at ordinary speeds. In such cases the time saved seems to justify the high cost of the tools. For the machining of soft materials such as cold-rolled steel and gray cast iron in small or medium-sized quantities, the present cost of tungsten carbide seems entirely too high to make it commercially practical."

Conclusion

Tungsten-carbide tools have been on the market for about a year and a half, but their use on production work is very limited as yet. A year ago it was thought that the development of tungsten carbide with respect to material and tools would progress much more rapidly than improvements would be made in adapting machines to the use of this material. This does not seem to have been the case. Improvements in the quality of the material, and in the efficiency of the tools and machines, seem to be advancing together. The improvement of the machines, however, is a large undertaking, and we may expect important changes in design for some time to come. A large amount of evidence proves that for certain classes of work, tungsten-carbide tools can be used with considerable economy on old-style machines provided they are in good condition. These tools are being experimented with by a large number of machine-tool users in an endeavor to adapt them to present machine set-ups. We need not expect that the transition from the use of old-style machine equipment to the use of highly developed machine equipment due to the more general adoption of tungsten-carbide tools will be unduly rapid.

The technique involved in the use of tungsten-carbide tools is quite different from that involved in the use of steel tools, and it will take some time to train shop people in the proper methods of handling, grinding, and setting up tools and machines. The development of this technique is rather expensive, but if the initial applications are made where appreciable saving can be effected, the cost of further and more difficult applications will be compensated for, at least to some extent. A wide demand for machine equipment from which maximum efficiencies can be obtained with the use of tungsten-carbide tools will undoubtedly develop with experience gained from applications on present equipment.

The Subcommittee extends thanks to the National Machine Tool Builders' Association for assistance rendered in the distribution of letters and questionnaires, and also to the many companies who responded for their well-prepared replies.

LETTER ACCOMPANYING QUESTIONNAIRE

Dear Sir:

A subcommittee on Tungsten Carbide Cutting Materials was authorized at the December, 1929, meeting of the A.S.M.E. Special Research Committee, and has since been organized. The members are as follows:

Prof. O. W. Boston, University of Michigan
W. A. Wissler, Union Carbide & Carbon Research Lab.
Coleman Sellers, 3rd, Wm. Sellers & Company
A. H. Bainton, Brown & Sharpe Mfg. Co.
Roger D. Prosser, Thomas Prosser & Son
G. N. Sieger, Carboloy Company
M. E. Lange, Warner & Swasey Company
T. G. Digges, Bureau of Standards
F. C. Spencer, *Chairman*, Western Electric Co., Inc.

The purpose of this Subcommittee is to correlate the research activities of various organizations, firms, and individuals with respect to tungsten carbide as a cutting material, and to investigate and report on the needs of the machine-tool industry in the matter of machine design as affected by the use of this new cutting material. To this end it is necessary that the Subcommittee consult with the metal-cutting industries and machine-tool builders in order that such information as is available may be correlated and disseminated in such a manner as to be of greatest value to these industries.

The Subcommittee would like to present a compilation of the obtainable data on the use of tungsten carbide tools at the Spring Meeting of A.S.M.E., which is to be held at Detroit in June, and solicits your aid in the preparation of such a report. If you will kindly have the engineer in charge of the introduction of tungsten carbide in your plant prepare a report covering a few typical examples of your experiences with this material, following the questionnaire attached the Subcommittee feels that you will be more than repaid for the trouble by receiving the combined report of a large number of experiences of other users. The compilation of this information will be expedited if the reply to each one of the lettered questions is made on a separate sheet. It is fully appreciated that it may be difficult to furnish information on every item. Please furnish, therefore, whatever information you have available. This should be received by May 1, 1930. After that date, the Committee would be glad to receive any further information you may obtain. The names of the concerns furnishing this information will not be published.

Kindly address communications to the Subcommittee on Tungsten Carbide Cutting Materials, A.S.M.E., 29 West 39th Street, New York, N. Y.

Subcommittee on Tungsten Carbide Cutting Materials,
F. C. Spencer, *Chairman*.

QUESTIONNAIRE COVERING THE USE OF TUNGSTEN CARBIDE AS A CUTTING MATERIAL

A—Extent of Application
- 1 Approximate number of operations on which used
- 2 Approximate percentage of tungsten carbide tools used to total tool equipment
- 3 Contemplated uses
  - *a* Nature of
  - *b* Number of.

B—Kind of Material Cut
- 1 Analysis
  - *a* Composition
  - *b* Heat treatment
  - *c* Condition of surface scale
  - *d* Physical characteristics.

C—Machine Equipment Used
- 1 Type
- 2 Conditon
  - *a* Good
  - *b* Fair
  - *c* Poor.

D—Tungsten Carbide Tools Used
- 1 Description
- 2 Method of tipping
  - *a* Dovetail

b Brazed
c Inserted
3 Size of tool shank
4 Shape of nose
5 Cutting angles
a Front and side rake
b Clearance angles
6 Limitations
a Used for a specific job
b Used for several jobs.

E—Grinding of Tungsten Carbide Tools
1 Method
2 Type of wheel used
3 Time consumed for grinding.

F—Method of Lapping Tools, if Done

G—Cutting Speeds Used in Feet Per Minute as Compared With Cutting Speeds of Tools Previously Used

H—Feeds Used in Inches Per Revolution or Stroke as Compared With Feeds on Tools Previously Used

I—Depth of Cut in Inches

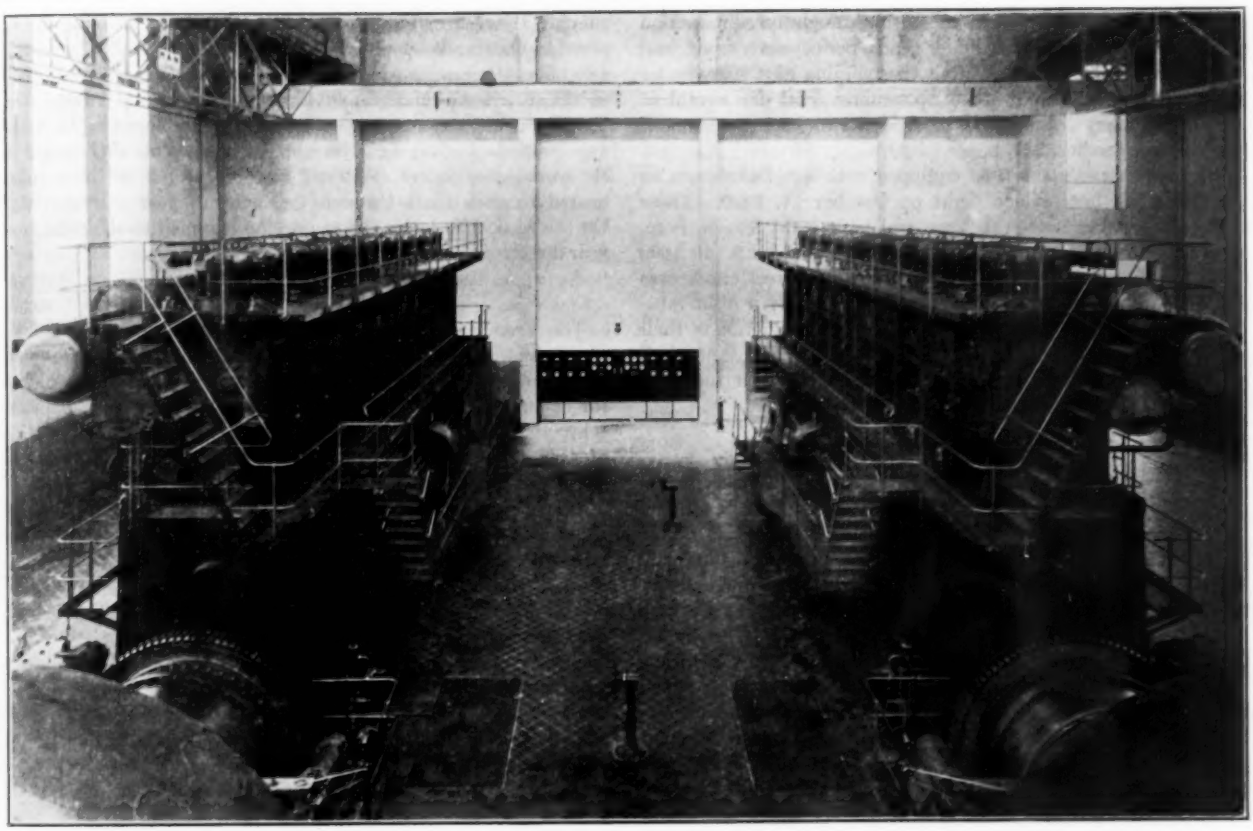
J—Economies in Percentage of Increased Output as Compared With
1 High-speed steel
a Number of pieces per grind
b Number of grinds in the life of the tool
2 Stellite
a Number of pieces per grind
b Number of grinds in the life of the tool.

K—Failures
1 Description of machine set-ups which failed
2 Corrective measures tried.

L—Suggestion for Design Changes of Machinery to Make Possible the Most Efficient Use of Tungsten Carbide Tools

M—Any Additional Information That Is Available, Such as the Attitude of Labor With Respect to This Material, the Difficulty of Training Operators in the Use of It, Difficulty of Tipping Tools and the Like Could Be of Value.

(Prepared by Subcommittee on Tungsten Carbide Cutting Materials and circulated with preceding letter.)



24,000-Hp. Peak-Load M.A.N. Oil-Engine Plant at Henningsdorf, Near Berlin, Germany

Progress in Oil- and Gas-Power Engineering*

Contributed by the Oil and Gas Power Division

Executive Committee: E. J. Kates, *Chairman*, L. H. Morrison, *Secretary*, H. A. Pratt, Harte Cooke, and L. M. Goldsmith

RECENT oil-engine developments have been revolutionary—during the last year oil engines of two widely different designs "went up in the air" in airplanes; a large British airship propelled with oil engines has just been commissioned; a 24,000-hp. stand-by and peak-load stationary power plant was recently started; a battleship with 50,000-s.hp. propelling plant has been laid down; and for the 100,000-hp. power plant of the new electrically propelled White Star liner, oil engines are being seriously considered. The principal reason for much of the progress has been the development of means to materially reduce weight and space requirements of oil engines and thus make them lighter and cheaper, thereby widening their field of application. Higher piston and rotative speeds, airless injection of fuel, supercharging of four-cycle engines, double-acting cylinder construction, special types of frame construction, improved materials—all of these have contributed to each individual success.

Aircraft Oil Engines

The Attendu experimental two-cylinder two-cycle engine,[3] built some time ago for the Navy Department in the hope of developing it for airship propulsion, gave disappointing results as to fuel consumption and thereby forfeited one of the expected advantages in large cruising radius—yet the new Packard airplane engine was the indirect result of this experiment. This engine, which first flew on September 19, 1928, later made the epochal 650-mile trip from Detroit to Langley Field on May 13, 1929, at a fuel cost for the trip of $4.68 instead of $25 for gasoline. This radial 9-cylinder engine develops 200 hp. at 2000 r.p.m. and weighs less than 3 lb. per b.hp.[1] A single automatic combination inlet-exhaust valve is fitted in each cylinder crown, and the propeller airstream is relied on to blow away the exhaust gases which the pistons force out and fill the cylinder on the suction stroke. A small single-plunger fuel pump is mounted ahead of each cylinder with a short pipe to the single injection valve. A special factory has been built by the Packard Company for the economical manufacture of these engines on a production basis. Henry Ford has also taken up experimenting with an oil engine for airplanes.

Last February in Germany another oil engine made several successful flights. Professor Junkers[2] modified his well-known opposed-piston construction to use two separate crankshafts

* Numbered references in the text relate to the Bibliography at the end of the report.

with the air propeller driven by both through 1:1.4 reduction gearing. Here the lack of cylinder heads, perfect scavenging, and equally perfect balance permitted the building of a six-cylinder 700-hp. engine running at 1600 r.p.m. on a total dry weight of 1780 lb. or about 2½ lb. per hp., while its fuel consumption on test is claimed to be 0.3971b. per b.hp-hr.

The British airship *R-101*,[3] equipped with five Beardmore oil engines, made her maiden flight on October 14, 1929. These engines are of the four-cycle type and have eight 8¼-in. bore, 12-in. stroke cylinders designed to develop 650 b.hp. at 1000 r.p.m., while their weight is 4600 lb. with cast-steel crankcases and 3600 lb. with aluminum ones. Unfortunately, considerable trouble from torsional vibration has forced the reduction of their rated speed—and therefore horsepower—and increased their unit weight. Airless fuel injection is used, and their fuel consumption is claimed to be 0.385 lb. per b.hp-hr.

Marine Oil Engines

The year marked the completion of the second Dieselization program of the U. S. Shipping Board, so that now a total of twenty-three single-screw vessels constitute the nucleus of the motorized American merchant marine. Eleven ships are equipped with double-acting engines, of which four are Worthington two-cycle four-cylinder units, four more are powered with M.A.N.-type two-cycle four-cylinder engines, and the remaining three are of the McIntosh & Seymour four-cycle type, one four-cylinder and two five-cylinder units. Of the nine ships equipped with single-acting engines, six have Busch-Sulzer two-cycle six-cylinder engines, while three others have McIntosh & Seymour four-cycle six-cylinder engines.

The three remaining conversions finished during the year are electric-drive ships with four trunk-piston McIntosh & Seymour engines driving electric generators, and a single propelling motor of 4000 s.hp. at 60 r.p.m. The engines are of the single-acting four-cycle type, rated to develop 1280 b.hp. at 250 r.p.m. in eight cylinders of 20 in. bore and 24 in. stroke.

Private enterprise in the United States has been responsible for only one larger motorship—a freight and passenger ship for the American and South African Line in which two 2700-s.hp., 95-r.p.m., four-cylinder, Sun Doxford two-cycle, opposed-piston engines of 21.26 in. bore and 85.04 in. combined stroke constitute the propelling plant.

Foreign Marine Oil Engines

The rest of the world has appreciated the advantages of the marine oil engine to a much larger degree—not less than twenty-seven motor passenger liners of over 10,000 tons were reported under construction in Europe and Japan last July. Of these, 13 are to be propelled by single-acting two-cycle engines and 3 by double-acting two-cycle, 10 will have double-acting four-cycle machinery, while only one will have an engine of the single-acting four-cycle type. Out of all the merchant vessels under construction, about 1,400,000 tons or 49.5 per cent are motorships,[4] with 1,238,675 i.hp. in oil engines to propel them or 54 per cent of the total horsepower of their propelling plants.

Of all the numerous types of propelling plant the following outstanding examples are to be noted. The recently launched White Star passenger liner *Brittanic* will be propelled by two ten-cylinder four-cycle double-acting engines of the Burmeister & Wain type, developing 10,000 s.hp. at 110 r.p.m. This is the largest engine with the same 33.071-in. bore by 59.055-in. stroke cylinder which was originally installed on the M.S. *Gripsholm* and of which more than 400,000 i.hp. have been built since. The four Dutch liners now under construction are to be propelled by two ten-cylinder (30 in. × 52¾ in.) two-cycle single-acting Sulzer engines developing 7000 s.hp. at 100 r.p.m., although a larger cylinder size has been repeatedly built up to seven cylinders, developing 7040 s.hp. at 100 r.p.m.[5] The other two notable propelling plants are the geared oil engines installed in the North German Lloyd liners *St. Louis* and *Milwaukee*. These are twin-screw vessels with two-cycle double-acting M.A.N.-type engines developing 3100 s.hp. at 225 r.p.m. (*St. Louis*) in six working cylinders of 19.097 in. bore and 25.98 in. stroke, geared to each shaft through the Vulcan hydraulic coupling.[6] On the M.S. *Milwaukee* the engines are coupled to the reduction gear direct.

Naval Oil Engines

The French submarine tender *Jules Verne*[7] has a propelling plant consisting of two eight-cylinder single-acting two-cycle Sulzer engines of the submarine type, one of which was ordered for experimental purposes in 1924 and developed on test 7000 b.hp. at 280 r.p.m., thus being by far the highest-powered engine of this type. These engines are installed so that they will develop only six-tenths of their speed and power in the ship.

The German faith in the oil engine as the most economical source of power served to develop it also into the lightest source of power for naval ships. The three German cruisers, the *Koenigsberg*, *Karlsruhe*, and *Koeln*, recently commissioned, have high-speed oil-engine cruising units in addition to their 65,000-s.hp. steam-turbine plant.

The now famous *Ersatz Preussen* received much of its military value in speed, guns, and protection through the ability of German engineers to develop an oil-engine propelling plant of 50,000 s.hp. which is actually lighter than any steam-turbine plant available.

Stationary Power Plants and Economics of the Oil Engine

Of the many hundreds of various stationary oil-engine power plants, the most notable is no doubt the installation of two double-acting two-cycle M.A.N. engines in a stand-by and peak-load plant at Henningsdorf, near Berlin, which was started last August. The engines have working cylinders of 23.622 in. bore and 35.433 in. stroke and can develop 11,700 b.hp. at 215 r.p.m. on a reported fuel consumption of 0.381 lb. per b.hp-hr. The engine is by far the largest engine using mechanical injection of fuel, and weighs only 55 lb. per b.hp. The simplicity of these large units is truly inspiring, but their resulting low cost, said to be $48 per kw., is also very important. Furthermore, with one man on watch the entire output of the plant (23,400 b.hp.) can be developed on two or three minutes' notice.

Railway Service

A total of 105 oil-electric locomotives were in service or on order in the United States and Canada by September 1, 46 of which were ordered during the year, as well as 35 switching locomotives ordered at one time by the New York Central for its New York west-side yards. These latter, in addition to the standard 300-b.hp. Ingersoll-Rand engine, have a 219-cell, 17-ton Exide battery and are arranged to operate also with outside current coming either through third rail or from an overhead collector. Of considerable interest is the Krupp locomotive for the Boston & Maine, scheduled for delivery before the year is over, in which a mechanical transmission with automatically operated magnetic clutches is used.

The Canadian National Railway has recently put into commission a large articulated locomotive housing in each cab one twelve-cylinder vee-type Beardmore four-cycle engine rated at 1340 b.hp. at 800 r.p.m.[8]

Supercharging and Two-Cycle vs. Four-Cycle

The old rivalry between two-cycle and four-cycle types of oil

engine continues. While even the Burmeister & Wain Company has developed a large double-acting two-cycle marine engine and another single-acting two-cycle high-speed engine which is being tried out in a locomotive and in a fishing boat; while the Werkspoor Company, and the Stabilimento Triestino (Italian licensee of Burmeister & Wain) have taken out licenses to build Sulzer two-cycle engines and Vickers has arranged to build two-cycle double-acting M.A.N. engines—while all of this seems to point one way, nevertheless the substantial development of supercharging of four-cycle engines gives this type of engine an advantage which cannot be overlooked, and its qualities have just begun to be appreciated. A recent paper[9] by the engineer-in-chief of the French Navy shows that even for a larger submarine propelling plant, substantial weight and space reductions are possible with supercharged four-cycle engines over all other possible types of oil engines.

A new type of supercharging became known during the year—the Werkspoor Company[11] utilized the underside of the piston of a crosshead type of single-acting engine for the purpose. Buchi[10] at the Swiss Locomotive Works and Rateau[12] in France both built exhaust-gas-driven turbo-blowers. The largest unit recently tested by the former comprised a 3000-b.hp. engine.

New Materials and Processes

The progress in the art of oil-engine building owes much to the perfection of the materials available for construction. The introduction of "nitralloy" steels having a glass-hard surface with a tough core has opened new possibilities for crankshafts (so far only small ones have been used), cams, pump plungers, and gears. Chromium plating was used in the Worthington engines for the Shipping Board, to produce a hard rubbing surface on a piston rod without affecting the elasticity necessary to withstand shocks of explosions. The extension of this process to cylinder liners is being perfected, and the building up of worn parts of plungers, valve stems, etc. may prove to be quite important for quick repairs.

The process of building up a lower cylinder head from steel parts by a copper soldering process[13] introduced by the German A.E.G. Co. for their large double-acting two-cycle engines,[7] will no doubt aid considerably in enhancing the reliability of large marine oil engines. Much experimental work is also being done to make welding of crankcases out of sheet-steel parts commercially feasible.

Oil-Engine Research

Spray research continues at the N.A.C.A. laboratories at Langley Field,[19] at Penn State College, and at the A.E.G. laboratories in Berlin. The effect of injection-tube length and diameter, injection pressure, valve-opening pressure, and initial tube pressure on the injection lag are being studied by means of spray photography at Langley Field. Work on the determination of the coefficient of discharge for small, round orifices as well as for multiple-orifice injection valves, continues.[14, 15, 16] The A.E.G. laboratories report investigations in progress on the size of oil drops in a fuel spray.

A very interesting method to determine whether engine, fuel, or lubricating oil is responsible for the difficulties experienced in burning certain varieties of fuel has been published by H. Jentzsch,[17] who developed an apparatus for testing the suitability of a given fuel by measuring the heat and oxygen required for self-ignition.

Gas Engines

The distribution of natural gas requires much power in gas-driven gas compressors—for the large pipe line from Louisiana to St. Louis twelve Worthington 1000-b.hp. units were installed during the year. The largest by-product source of energy is blast-furnace gas, and the Bethlehem Steel Company reports the installation of five of their 47-in. × 84-in. × 60-in. tandem gas-driven blowing engines. During the year the Allis-Chalmers Company designed and built two of their largest (60-in. × 64-in. cylinders) twin tandem gas engines, to be operated also on blast-furnace gas. The first plant in this country to be run successfully on sewage gas has been installed in Charlotte, N. C.,[18] where one 55-b.hp. and one 225-hp. standard Sterling gasoline engines were used. The Deutz Company installed an 1120-b.hp. power plant near Berlin working on sewage gas, and has another similar plant of 2100 hp. in course of construction.

E. C. Magdeburger, *Chairman*,
Progress Report Committee, Oil and Gas Power Division.

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Service Characteristics of Diesel-Engine Lubricating Oil

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Diesel-engine lubrication has presented difficulties owing to the high compression pressures and the high temperatures and to the great weight of engine parts. Results are given of a study of the progressive record of the characteristics of the lubricating oil used in a Diesel engine in regular service for about a year installed in a freight-switching locomotive running 23 hours of the day.

LUBRICATION of Diesel engines has presented serious difficulties, due to the high compression pressures, high temperatures, and great weight of the engine parts. Dr. Diesel himself has stated that his first engine ran only three revolutions, when first started, before stoppage was caused by the seizing of the piston rings; just long enough to demonstrate that it was possible to get ignition by compression. Service records of operating expenses usually have shown that the lubricating oil may cost from 10 to 25 per cent as much as the fuel oil.

It has seemed worth while to publish the results of a study of the progressive record of the characteristics of the lubricating oil in use in a Diesel engine in regular continuous service over a period of nearly one year. This Diesel engine was in operation on a combination battery-third-rail Diesel-electric locomotive employed upon switching service on the freight tracks of the New York Central Railroad on the West Side in New York City. The locomotive is in continuous service and the engine actually running about 23 out of every 24 hours.

Description of Engine

The engine upon which these tests were made was manufactured by the Ingersoll-Rand Company and installed on New York Central Railroad locomotive No. 1525. A view of the exterior of this engine is given in Fig. 1. The description is as follows:

Rating, 300 b.hp.; maximum speed, 550 r.p.m.; engine cycle, four-stroke; pistons, trunk type; number of cylinders, six; arrangement of cylinders, vertical; bore, 10 in.; stroke, 12 in.; piston speed, 1100 ft. per min.; mean effective pressure, 76 lb. per sq. in.; weight, without generator, 20,125 lb.; overall length, 12 ft.; overall height, 7 ft.; overall width, 3 ft. 3 in.; method of starting, using generator as motor on battery; fuel injection, direct solid injection; injection pressure, 3000 lb. per sq. in.; fuel distribution, single fuel pump and distributor.

The cylinder walls and cylinder head are jacketed and water-cooled. The water is cooled in turn by air-cooled radiators installed overhead at the end of the locomotive with blast fans for forced air-cooling.

The cooling water usually entered the engine at about 150 deg. fahr., and left at about 160 deg. fahr., and the lubricating oil was kept down to temperatures not very much greater than that of the cooling water.

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Sponsored by the A.S.M.E. Special Research Committee on Lubrication and presented at its session during the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Description of Lubricating System

Lubrication of the Diesel engine is provided by a forced-feed oil pump taking oil from the crankcase, which held a supply of 54 gal., and delivering approximately 12 gal. per min. to the engine's main bearings. Holes in the crankshaft webs conduct oil to the connecting-rod bearings and up through holes in the connecting rod to the wristpin.

The cylinder walls obtained their supply of lubricating oil partly by splash from the crankcase, but mainly by overflow from the wristpin.

The lower end of the piston had the usual oil-wiper rings with drain holes leading back to the inner surface of the trunk piston.

The lubricating oil was continuously purified by the circulation of about 17 gal. per hour through a De Laval 17-H size disk clarifier operated at 7000 r.p.m. In this way the equivalent of the full content of the system was purified every three hours.

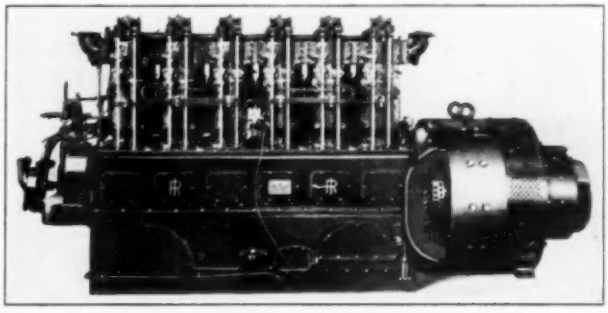


Fig. 1 Ingersoll-Rand 300-Hp. Locomotive Oil Engine Showing Oil Distributor Side and Generator

In some later runs the purifier throughput was changed to about 11 gal. per hour (i.e., a purification equivalent to about once in five hours) to try the effect of giving an even higher degree of clarification to the oil that was purified.

Test Methods Employed

All of the tests made upon the characteristics of the oil were carried out in accordance with the Standard or Tentative Standard Methods of Test adopted by the American Society for Testing Materials.

During the course of the work it was found desirable to improve upon the standard method for measuring the volume of sediment by means of the centrifuge, since a speed of 1500 r.p.m. on a 100-cc. test tube swung on a 17-in. circle took too long to settle out completely the carbonaceous sludge (about 10 hours being required). A new type De Laval test-tube centrifuge became available during the course of this work, operating at 4500 r.p.m., which reduced the settling time required to about one-fifth or less and in addition packed the sediment into a much smaller volume, thus giving a more representative figure for the amount of sludge.

Other methods of test, as well as further prolongation of the time of centrifuging the standard A.S.T.M. 100-cc. test tube at 4500 r.p.m., proved that *all* the sediment had been removed from the oil. The original red color was restored; in fact, even

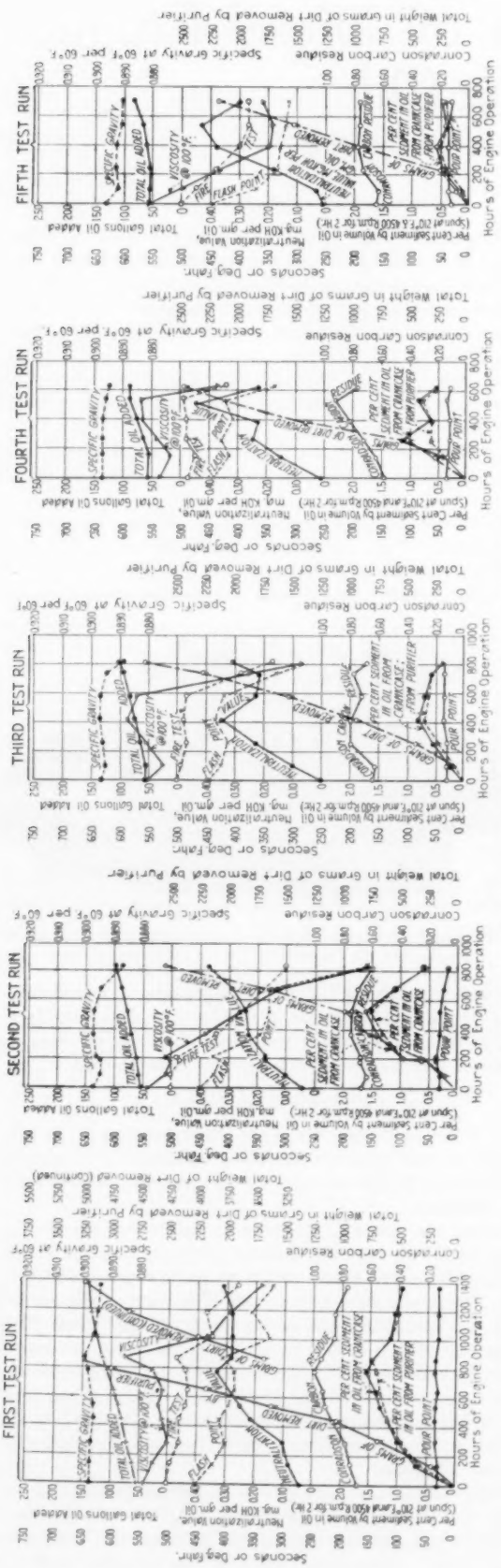


FIG. 2 PLOTTED CHARACTERISTICS OF THE OIL FOR FIVE RUNS

a lighter colored pale-yellow clear oil was obtained by extremely prolonged centrifuging.

During the course of this work it was found that for this kind of sediment the packing at 4500 r.p.m. gave a final sediment volume of only 62.3 per cent of that by centrifuging at the standard test speed of 1500 r.p.m.

By completely separating out all the sludge it was possible to make all the oil tests on samples of oil from which all sludge had been removed and so determine the characteristics of the residual oil itself.

CHARACTERISTIC CHANGES IN THE OIL

The changes (if any) in the characteristics of the lubricating oil are fully shown in the accompanying curve sheets plotted against hours of engine operation. The original characteristics of the new oil were as follows:

Specific gravity at 60 deg. fahr.	0.897
Flash point, deg. fahr.	450
Fire test, deg. fahr.	500
Pour point, deg. fahr.	30
Saybolt viscosity at 100 deg. fahr.	540
Saybolt viscosity at 210 deg. fahr.	66
Steam emulsion, S. E. No.	144
Neutralization No.	0.04
Color	Red
Conradson carbon residue	0.67
Sligh oxidation No.	9.7

The values for specific gravity, flash point, fire point, pour point, Saybolt Universal viscosity at 100 deg. fahr., carbon residue (Conradson method), neutralization number, and per cent sediment in the oil are given, as well as the total sediment removed from the oil and the quantity of oil used.

Examination of the curves for these tests (as well as comparisons with other engines) shows that service (when not affected by fuel dilution) tends somewhat to increase the gravity, fire and pour points, increase the viscosity and carbon residue, and to appreciably increase the neutralization number. The flash point tends to be decreased slightly, presumably as a result of cracking of some of the oil.

These changes are controlled, in part, by the amount of make-up oil added to the system, but for most of the runs recorded here the effect of fuel dilution was eventually predominant, causing an appreciable decrease of the gravity, flash, fire, and pour points, and of viscosity and a slight decrease in carbon residue.

Fuel dilution may come about in small part as direct leakage past the piston rings, but it would seem that this is negligible except when for some reason some cylinder fails to fire. Failure to fire on one cylinder occurred on Feb. 26, 1929, during the first run and resulted immediately in cumulative dilution, which finally reached a value of about 8 or 9 per cent. Fuel dilution may also result from pipe or pipe-fitting breakage, gasket leakage, or spillage around the engine. Whenever such causes were identified, they were of course corrected as quickly as possible.

Consideration of the increase of neutralization value and of the increase of carbon residue leads to the conclusion that to some extent the service in Diesel engines causes some oxidation as well as some cracking and some burning of the oil, not through any defect in the oil, but as a normal result of the necessarily severe service.

It will be noted that the engine crankcase was drained and refilled with new oil for each of the runs described herein, but there is no indication from the results of these tests that it may not be both feasible and desirable to leave the lubricating oil permanently in the engine without ever having to drain the crankcase, provided it is kept continuously clarified to a suitable degree.

When the sludge is removed at the same rate as it is produced the sludge content of the oil after filling the crankcase with new oil rises during the first part of the run and then stabilizes at a moderate value which is only so high as may be needed for the time and heating required to agglomerate the sludge to the settling and separating point.

During the course of these runs the sludge never reached 2 per cent by volume of the oil and usually the maximum was 1 per cent or less.

It may be desirable to remove the oil because of some accidental occurrence, such as fuel dilution, as in some of these runs, or the need for complete overhauling of the engine. When removed the oil may be given a simple but very effective treatment for reclamation, including a readily applied method for taking out fuel dilution, if any be present.

Character of the Sludge From Diesel-Engine Lubricating Oil

The sludge that separates from Diesel-engine lubricating oil is mainly carbonaceous matter. From a new engine, however, large amounts of free iron (fine chips and filings or initial-wear particles) and sand (presumably core sand from the inner walls of the castings) may be found. Some sand, probably picked up from the roadbed and carried into the engine through the breather connections or with the oil used for combustion, seemed to be present throughout the runs. As the run proceeds, both metallic oxides (principally iron with small amounts of copper, tin, and antimony) and silica decrease from their initial values to the practically constant and quite small proportions of 1 to 2 per cent of the oil-free total for silica and 5 to 10 per cent for metallic oxides. The carbonaceous matter is absent from new oil at the start of a run, reaches a maximum after several hundred hours, and then decreases or remains practically constant at values of 0.5 to 1.5 per cent of the volume of the oil. Even when packed tightly the sludge carries with it, in the interstices, a large proportion of oil, amounting to about 50 per cent of the total sludge, by weight and slightly more by volume. The sludge and the oil itself were practically free from water.

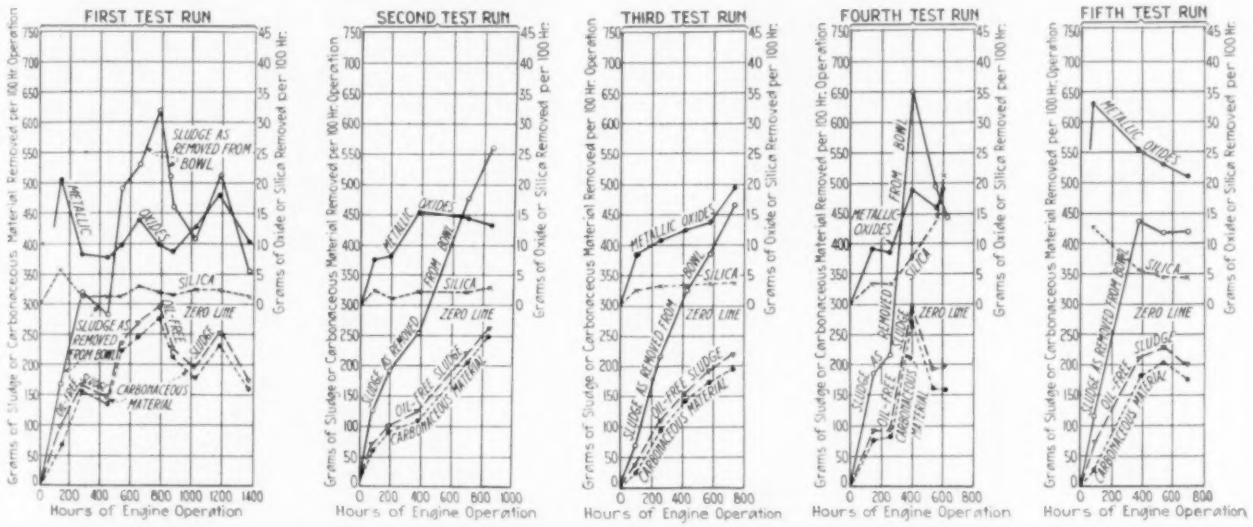


Fig. 3 Plotted Characteristics of the Sludge for Five Runs

	FIRST TEST RUN										SECOND TEST RUN						THIRD TEST RUN					FOURTH TEST RUN					FIFTH TEST RUN			
HOURS OF ENGINE OPERATION BETWEEN SAMPLES.	141	137	168	96	109	133	90	142	158	195	85	105	181	158	158	155	102	160	160	156	158	153	111	136	145	79	85	(2 wk) 311	143	159
CUMULATIVE HOURS OF ENGINE OPERATION.	141	278	446	542	651	784	874	1016	1174	1369	85	190	371	529	687	842	102	262	422	578	736	153	264	400	545	624	85	396	539	698
	ANALYSIS OF SLUDGE AS REMOVED FROM BOWL OF PURIFIER																													
PER CENT BY WEIGHT OF OIL.	40.8	48.5	49.7	51.6	49.7	53.2	50.7	52.7	50.6	51.7	43.2	47.2	50.5	50.9	52.7	52.5	47.0	48.8	51.6	49.8	52.4	51.0	57.4	54.4	61.0	55.1	37.8	51.2	45.2	52.3
PER CENT BY WEIGHT OF CARBONACEOUS MATERIAL.	43.2	48.4	47.1	46.1	47.1	45.0	47.1	43.7	45.4	44.9	48.9	48.0	42.5	45.8	43.7	44.5	38.0	44.8	43.6	45.6	42.8	42.1	37.2	41.5	32.9	35.8	22.1	41.8	48.3	41.7
PER CENT BY WEIGHT OF METALLIC OXIDES.	12.6	2.6	2.7	2.0	2.6	1.5	1.9	3.1	3.5	2.9	5.8	4.2	6.0	2.9	3.1	2.4	11.5	5.1	3.8	3.6	4.2	5.0	4.0	2.9	3.2	4.3	29.1	5.8	5.5	5.0
PER CENT BY WEIGHT OF SILICA.	3.4	0.5	0.5	0.3	0.6	0.3	0.3	0.5	0.5	0.5	2.1	0.6	1.0	0.4	0.5	0.6	3.5	1.5	1.0	1.0	0.8	1.9	1.4	1.2	2.9	4.8	11.0	1.2	1.0	1.0
	ANALYSIS OF SLUDGE ON OIL-FREE BASIS																													
PER CENT BY WEIGHT OF CARBONACEOUS MATERIAL.	73.0	94.0	93.6	95.3	93.6	96.1	95.5	92.4	91.9	93.0	86.1	90.9	85.8	91.2	92.4	93.7	71.8	87.0	86.0	91.0	89.5	85.9	87.3	91.0	84.4	79.8	35.5	85.7	88.2	87.4
PER CENT BY WEIGHT OF METALLIC OXIDES.	21.3	5.0	5.4	4.1	5.2	3.3	3.9	6.6	7.1	6.0	10.2	8.0	12.2	6.0	6.5	5.0	21.6	9.9	10.0	7.1	8.8	10.2	9.4	6.4	8.2	9.5	48.7	11.9	9.9	10.5
PER CENT BY WEIGHT OF SILICA.	5.7	1.0	1.0	0.6	1.2	0.6	0.6	1.0	1.0	1.0	3.7	1.1	2.0	0.8	1.1	1.3	6.6	3.1	2.0	1.9	1.7	3.9	3.3	2.6	7.4	10.7	17.8	2.4	1.9	2.1
RATIO OF CARBONACEOUS MATERIAL TO METALLIC OXIDES	3.4	18.8	17.3	23.2	18.0	29.1	24.5	14.0	13.0	15.5	8.4	11.3	7.0	15.2	14.2	18.7	3.3	8.8	8.8	12.9	10.2	8.4	9.3	14.2	10.3	8.4	0.8	7.2	8.9	8.3

Fig. 4 Tabulated Data for the Analyses of the Sludge

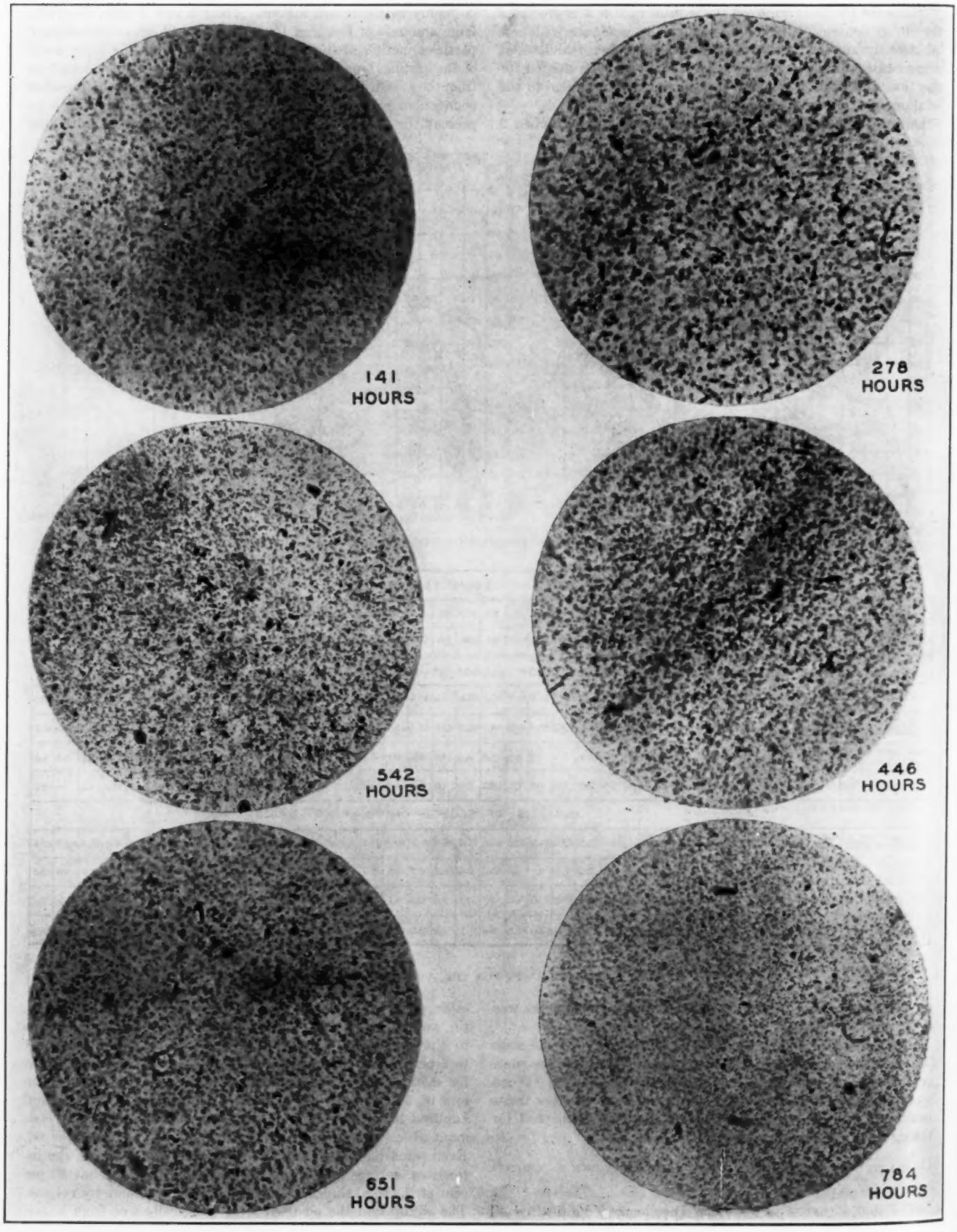


FIG. 5 (*a*) PHOTOMICROGRAPHS OF LUBRICATING OIL REMOVED FROM CRANKCASE × 470

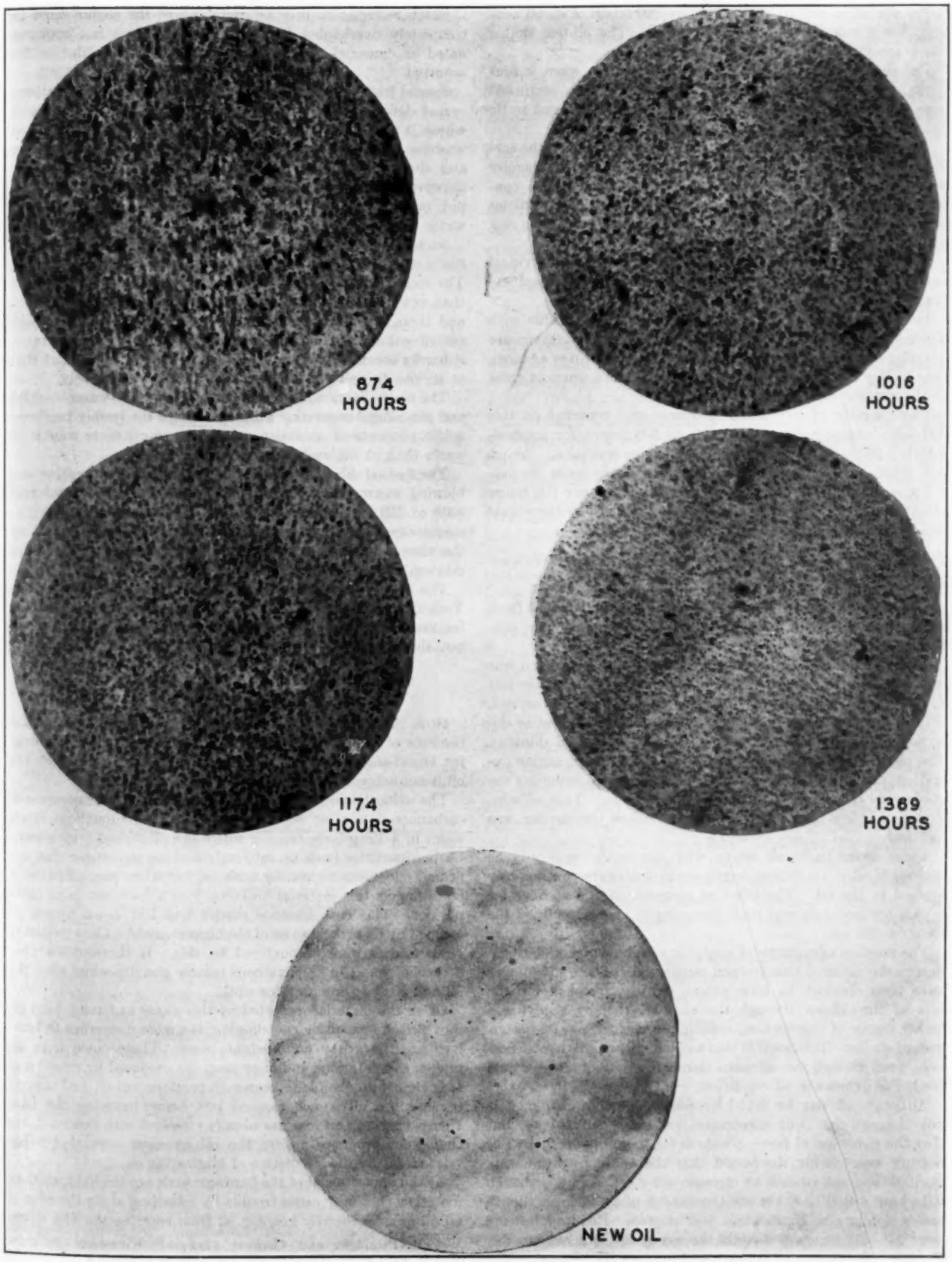


FIG. 5 (*b*) PHOTOMICROGRAPHS OF LUBRICATING OIL REMOVED FROM CRANKCASE × 470

The sludge, as settled out and before extraction of its oil content, has a gross specific gravity of 1.11. The oil-free sludge has a specific gravity of 1.2 to 1.5.

The sludge, especially the carbonaceous matter when it first forms, consists of extremely minute particles. With continued time and heating these particles tend to agglomerate and settle out, or are removed by centrifuging.

The higher the degree of clarification applied to the oil the earlier in the agglomeration stage can the sludge be removed, thereby serving two useful purposes—first, stabilizing the sludge content at lower values and, second, keeping whatever particles may be present nearer the colloidal state and so less able to clog passages, settle on walls, or wear the running parts.

The appearance of the sludge and the size of the individual particles are shown in the photomicrographs with a magnification of 470 times.

Individual particles (or groups of particles) are visible with dimensions of one-thousandth of a millimeter, and there are irregular-shaped agglomerates that are five to ten times as large, thus having a mass one hundred to one thousand times as great as the smaller visible particles.

The quantity of oily sludge produced and removed on this 300 b.hp. engine amounted to 300 to 400 grams (or approximately 0.65 to 0.90 lb.) per 100 hours of engine operation. About half of this sludge is the oil which fills the space between the particles, so that on the dry basis 150 to 200 grams per 100 hours of engine operation of "dry sludge" was produced by the engine and removed by the continuously operated purifier.

Purification and Reclamation of Diesel-Engine Lubricating Oil

The engine crankcase had been drained and refilled with fresh new oil monthly prior to the installation of the continuous centrifugal clarifier.

In the first run the oil was kept in service ten weeks and was removed primarily in order to allow the starting of another test and to get a check upon the progress of the changes observed. Other runs were shorter, not because the oil had sludged or deteriorated, but because of engine changes or fuel-oil dilution. The make-up oil needed was 6 gal. per 100 hours of engine operation, and only 10 gal. per 100 hours was needed including the oil drained out at the end of the 10-week run. This oil consumption is less than half that needed before the clarifier was installed.

There seems to be no reason why the crankcase should be drained of oil, if a sufficient degree of clarification be continuously applied to the oil. The effect of stoppage of the clarifier for even a few hours showed itself immediately in the results of the tests on the oil.

The possible advantages of applying a high degree of clarification to the oil have already been mentioned. These advantages have been checked, to some extent already, by changing the rate of throughput through the clarifier, thereby applying a higher degree of clarification, resulting in cleaner oil and better-packed sludge. It is possible that a still higher degree of clarification, even though the oil were clarified less frequently, would further improve the oil condition.

Although oil may be saved by continuous clarification, it is not thought that this constitutes its major advantage, but that the reduction of bearing wear is far more important. The bearing wear during the period that the oil was continuously clarified was not enough to measure after ten weeks, although it had amounted to about one-thousandth of an inch per month before continuous clarification was started. Reduced bearing wear not only increases directly the engine life, but reduces cost of labor for take-up of bearing and outages for repairs.

Batch reclamation may be useful where the engine must be completely overhauled or where some accident has contaminated or damaged the oil or where fuel or other dilution has occurred.

Special tests have shown that heating and allowing a settling period definitely assist in agglomerating the sludge to a point where it is readily removable. Other tests have shown that washing with clean boiling water and then removing the water and sludge together in a centrifugal separator tremendously improves the centrifuging process, allowing purification throughput rates about 100 times greater than purification without water washing.

Such simple treatments will restore all the original properties except color and to some extent neutralization number. The reclaimed oil is clean and free of sludge, but usually darker than new oil. It is not believed that color, per se, is important, and though it might be restored by applying excessively high centrifugal clarification treatment at very low throughput rates, it hardly seems economically justifiable in view of the fact that in service the oil will be darkened almost immediately.

The neutralization number is improved by the water-washing and centrifugal-separation process, because the freshly produced acidic products of oxidation, which are much more soluble in water than in oil, are removed.

The fuel-oil dilution, if any, may be removed by heating and blowing steam directly through the oil. A high temperature (200 to 250 deg. cent.) and the use of superheated steam (i.e., steam expanded down from 250 lb. per sq. in.) greatly reduce the time required and the steam consumption needed for fuel dilution removal.

The authors are indebted to the representatives of the New York Central Railroad and of the De Laval Separator Company for much direct assistance and for facilities afforded to carry out the work.

Discussion

H. A. S. Howarth.[3] It would be interesting to learn whether the rate of sludge formation with a given oil is much different for Diesel-engine service than for some other one in which the oil is not subjected to such heated wall contacts.

The writer had occasion many years ago to note the presence of carbonaceous matter deposited by warm oil throughout interstices in a Kingsbury bearing where the oil flowed very slowly. Carbon particles built up into ugly looking structures that appeared dangerous to bearing surfaces, but when pressed between one's fingers this material broke up into a harmless impalpable powder. This carbonaceous matter was laid down by an oil claimed by its makers to be of the highest grade. Only moderate temperatures were encountered by this. It threw down very little sludge. The carbonaceous matter was deposited after the oil had passed through filter cloth.

Of all the materials reported by this paper as having been removed from the oil by centrifuging, the most dangerous to bearings are the gritty and metallic ones. These come from oil piping, cast interiors, and loose particles produced by machining. It is almost impossible to keep such particles out of the bearings, because the oil is not cleaned just before entering the film. Hence bearing surfaces are usually streaked with fine scratches that were produced before the oil passages were thoroughly washed out by the circulation of lubricating oil.

At the opposite end of the hardness scale are the light, cottony materials that may cause trouble by collecting along the edge of an oil groove, thereby keeping oil from entering the film space.

[3] Vice-President and General Manager, Kingsbury Machine Works, Frankford, Philadelphia, Pa. Mem. A.S.M.E.

Such substances are probably adequately removed by fine wire screens placed as near the bearings as practicable.

When installing Kingsbury thrust bearings in the days when central-station oiling systems were the rule, we advised the user to heat the oil in his system, then to bypass the bearings and to circulate the oil until the filters showed no injurious materials present. Even then we advised the use of muslin bags over the ends of the oil inlet pipes within the bearing housing for a few weeks.

Users of bearings in high-grade machinery understand fairly well today that they must keep dirt out of the oil. Yet it is a common experience to see mechanics in filthy overalls standing over bearings and lifting clean parts in or out. And they are trying to keep the bearings clean. The sum total, however, of the care exercised by those dealing with fine bearings must be quite satisfactory nowadays, because the failures of such oil-film bearings are indeed very rare occurrences.

H. C. Dinger.[4] This paper is of special interest as indicating in a rather definite manner that the more or less continual clarifying of the Diesel lubricating oil and the addition of new oil to make up for leakage, oxidation, and evaporation will enable the lubricant to be kept in excellent condition without requiring frequent dumping and replenishment of the whole sump. The contamination to be expected is much less than with gasoline engines because of the absence of the light ends.

The Engineering Experiment Station, Annapolis, has checked the condition of lubricating oil on Navy submarines covering considerable periods, and the writer would like to offer some general observations as reflected by those investigations which conform rather closely to the results reported in this paper.

The following conclusions were drawn from the examination of a large number of used Diesel-engine lubricating oils from submarines, the submarines being equipped with centrifugal purifiers:

(*a*) A slight increase in specific gravity of the oil
(*b*) A considerable decrease in flash point in both open- and closed-cup apparatus
(*c*) A considerable decrease in fire point
(*d*) Pour point not much affected
(*e*) A slight decrease in viscosity
(*f*) The oil is darkened in use, but not to nearly as great an extent as encountered in internal-explosion engines (gasoline engines)
(*g*) No development of mineral acidity in the oil
(*h*) Neutralization number, precipitation number, and carbon residue are increased to practically the same extent as encountered in a force-feed turbine lubricating-oil system
(*i*) The nature of the carbon residue in the oil is not changed, nor is there any appreciable increase in ash
(*j*) The non-emulsifying properties of the oils were considerably affected
(*k*) Not any of the samples contained more than a trace of water.

It appears from all the information available that the contamination of the used lubricating oil of Diesel engines from the fuel is, in general, very slight.

The foregoing conclusions are in fair agreement with the results obtained by Dr. Flowers and Mr. Dietrich and show that centrifugal purification of the lubricating oil of Diesel engines is fairly satisfactory and that complete renewal is necessary only at special times when a complete cleaning of the crankcase is desired.

Eugene P. Kiehl.[5] The Diesel engines to be described by the writer are in operation as power-generating units, operating continuously at 90 per cent load factor, at the Philadelphia plant of the Atlantic Refining Company. These engines have been in continuous service for approximately four years, coming down only for repairs.

The engines upon which this information is based were manufactured by the Rathbun-Jones Engineering Company for the Ingersoll-Rand Company and were installed in No. 1 power house. The description is as follows:

Rating, 840 b.hp.; speed, 214 r.p.m.; engine cycle, four-stroke; piston, trunk type; number of cylinders, six; arrangement of cylinders, vertical; bore, 19½ in.; stroke, 24 in.; piston speed, 856 ft. per min.; mean effective pressure, 68 lb. per sq. in.; overall length, 25 ft. 6 in.; overall width, 11 ft.; overall height, 13 ft.; method of starting, air; direct solid injection; injection pressure, 3000 to 5000 lb. per sq. in.; fuel distribution, single-feed pump and distributer per engine.

The cylinder walls and cylinder head are jacketed and water cooled. In winter this water is recirculated.

The cooling water enters the engines at about 80 deg. fahr. and leaves at about 100 deg. fahr., the lubricating oil being kept down to temperatures not very much greater than that of the cooling water, 110 to 130 deg. fahr.

Lubrication of these engines is provided by an oil pump taking oil from the crankcase and delivering it to the piston sump tank, from which the oil is circulated to the piston cooling pump and the centrifuge. Oil is fed to the bearings by gravity through sight feeds. Holes in the crankcase webs conduct oil to the connecting-rod bearings, and through holes in the connecting rod to the wristpin.

The cylinder walls and camshaft bearings obtain their lubrication chiefly by splash from the crankcase. The lower end of the piston has one oil-wiper ring with the drain holes leading back to the inner surface of the trunk piston.

The lubricating oil is continuously purified by circulation through a Sharpless clarifier operated at 17,000 r.p.m. for six hours per day on each of the four engines. The amount continuously purified is 5000 gal. per 24 hours.

A weighed sample was dissolved in special solvent (70-deg. naphtha) and filtered through a weighed Gooch crucible. The latter was dried at 212 deg. fahr. and weighed. This residue was then washed with benzol, dried at 212 deg. fahr., and weighed.

A separate sample was ashed, the ash washed on a filter paper with hot water, and the filtrate tested for sodium sulphate. The water-insoluble portion was digested with hydrochloric acid, the acid-insoluble portion was calculated as silica, while the soluble portion was taken as combined oxides.

The portion soluble in naphtha was calculated as oil, while that insoluble in naphtha but soluble in benzol was calculated as asphaltic. Carbonaceous material was taken as 100 (ash plus asphaltic plus oil).

With this method of testing it was impossible to test the oil contained in sludge for its characteristics. The original characteristics of the new oil are as follows:

A.P.I. gravity at 60 deg. fahr.	26
Flash point, deg. fahr.	440
Fire test, deg. fahr.	505
Saybolt viscosity at 100 deg. fahr.	504
Saybolt viscosity at 210 deg. fahr.	63
S. E. No.	120
Color, N.P.A.	4½–4¾
Conradson carbon residue	0.460
Fuel dilution (no record kept)	.....
Pour point, deg. fahr.	25

The engine has never had the oil completely renewed at one time as there has been no indication of the desirability of changing.

The analysis of the sludge as removed from the bowl of the purifier is as follows:

[4] Captain, U. S. Navy, Officer-in-Charge, Engineering Experiment Station, Annapolis, Md. Mem. A.S.M.E.

[5] Power Engineer, Atlantic Refining Company, Philadelphia, Pa. Mem. A.S.M.E.

	Oil	Asphaltic	Carbonaceous	SiO_2	Na_2SO_4	Combined oxides
Sludge from centrifugal bowl (4 p.m., 11/26/29)	48.05	4.41	43.12	0.533	0.343	3.54
Sludge from centrifugal bowl (midnight, 11/26/29)	47.18	5.18	43.80	0.322	0.291	3.22
Sludge from centrifugal bowl (8 a.m., 11/27/29)	49.23	8.11	39.93	0.379	0.305	2.05
Average	48.15	5.90	42.28	0.411	0.313	2.90

The sludge that separates from Diesel-engine lubricating oil is chiefly carbonaceous matter. The sludge as removed from our separator has the consistency of soft rubber and carries with it approximately 50 per cent of oil.

The quantity of sludge produced and removed on these 840-hp. engines amounts to 12.3 lb.[6] per 24 hours of centrifuging, including the oil. When first installed, the bowl of the centrifuge was removed and cleaned once a day, about 8.5 lb. of sludge being deposited. When the bowl is cleaned once every eight hours, we get an increase of 2.8 lb. per day, or 33 per cent by weight.

Authors' Closure

Mr. Hersey's comments suggested by Dr. H. T. Kennedy of the Bureau of Standards requested information upon the fuel oil used. Information in regard to this is given, having been worked up since the presentation of the paper. We do not have, however, information upon the mixture ratio employed for the engine.

The characteristics of the fuel oil used on Diesel-electric locomotive No. 1525 of New York Central Railroad are reported as follows:

Property	Unit	
Specific gravity at 60 deg. fahr.	Water at 60° F.	0.844 = 36.2° A.P.I
Flash point	°F.	215
Fire test	°F.	250
Pour point	°F.	−10
Saybolt viscosity at 100 deg. fahr.	Sec.	37
Saybolt viscosity at	Sec.	.....
Steam emulsion, S. E. No.	Sec.	.....
Neutralization No.	mgKOH/gm	0.28
Color	....	.....
B.S. and water by centrifuge, bottom drain sample	%	0.62
B. S. centrifuge	%	.....
Water centrifuge	%	.....
Water distillation	%	.....
Conradson carbon residue	%	0.04
Slight oxidation No.	mg/10gm	
Sulphur	....	0.262

The sulphur was determined by the bomb method, using an

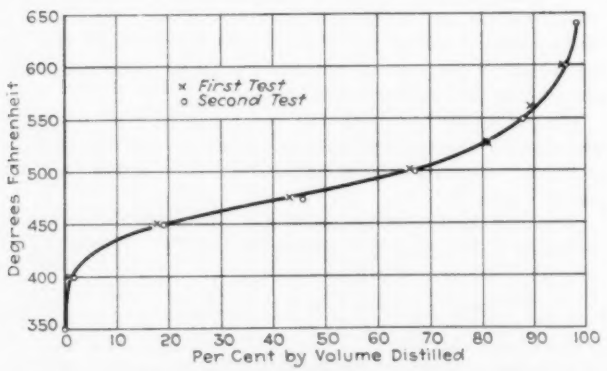


Fig. 6 Distillation Curve of Fuel Oil Used on New York Central Railroad Locomotive No. 1525

Emerson calorimeter. The distillation curve of the fuel oil is given in Fig. 6.

There is no evidence that dilution in the lubricating oil occurs in the way and to the extent found in gasoline-automobile engines (except in the case of a cylinder failing to fire), and dilution does not seem to occur under normal operating conditions, so far as we have been able to find.

The examination of the character of the sludge in terms of its solubility in benzol, chloroform, etc., has been made[7] since the presentation of the paper and is given in the report herewith.

The samples analyzed were taken during the test runs on locomotive No. 1525 on February 26 and March 19, 1929. The analysis is as follows:

ANALYSIS OF SLUDGE ON OIL-FREE BASIS

	Feb. 26	March 19
Benzole-soluble material, per cent	20.6	27.9
Choloroform-soluble material, per cent	3.5	5.1
Insoluble carbonaceous material, per cent	71.4	60.0
Metallic oxides, per cent	3.9	6.0
Silica, per cent	0.6	1.0

The high percentage of insoluble carbonaceous material indicates that the sludge is formed more by cracking of the oil than by oxidation.

The authors were impressed by the statement that, in Dr. Kennedy's opinion, settling, if sufficiently prolonged, would render the lubricating oil essentially as good as new, and the further confirmation of this new point by Captain Dinger.

The authors are obliged to Mr. Hall for his observations on the quantity of sludge removed from the lubricating oil of 840-hp., 214-r.p.m. engines of 12 lb. per 24 hours at first, 8 lb. per 24 hours later, when using a lubricating oil of 504 seconds viscosity at 100 deg. fahr., and his further observation of the desirability of frequent cleaning of the centrifuge bowl.

The answer to Mr. Howarth's question as to the collection of sludge on the crankcase walls is that such deposits occurred before centrifugal purification was practiced, but deposits did not occur afterward.

It was interesting to hear from Mr. Howes that where the crankcase is separate from the cylinder he had observed more sludge produced in the crankcase than on the cylinder walls, and the concurrence in this by Mr. Codding.

We have checked the condition of the crankcase walls on a large marine engine with a separate crankcase chamber after one year's service. In this case a large centrifugal oil purifier was in operation, and the crankcase walls were as clean as new surfaces.

Mr. Codding's question as to rate of addition of oil make-up is answered by the plotted curves, which show a fairly frequent addition of make-up oil, in moderate amounts compared to the volume of oil space in the crankcase.

Dr. Dickinson appears to consider that there may be some advantage in having a large volume of lubricating oil in the crankcase and so allowing time for impurities to settle out. We are not sure that this is the best practice when a powerful centrifugal clarification can be employed continuously, although it may be useful where no clarification is available.

There would seem to be some advantage in keeping the oil volume small when vigorously clarifying it, as the total volume of oil is then more frequently clarified and the fully clarified oil is contaminated by a smaller volume of dirty oil when returned and mixed with the mass of oil in the crankcase. The ideal arrangement would seem to be to feed only clarified oil to a pressure-lubrication system, to eliminate splash lubrication, and to have practically no oil at all in the crankcase. In such a system the amount of oil would be restricted to the minimum value and would be large enough only to insure against the sudden loss of all lubricant through an unobserved leak.

[6] Approximately 6 per cent of the make-up added.

[7] Report made on December 18, 1929.

The Gas Engine and Its Application in Oil-Field Engineering

By GEORGE L. REID,[1] OIL CITY, PA.

The paper presents specific information in regard to engineering problems and progress relative to the processes of oil lift. Drilling is accomplished by two methods in the United States. The older one is by the cable tool, standard, or percussion system, and the later one is by the rotary system. Engineering in respect to drilling is on a firm basis. The geologist has predetermined the structures. The tools and power requirements are known within a close factor of accuracy. In order to reduce the tremendous losses sustained through dry holes or wells which fail to pay for themselves, it was necessary that scientific methods be developed.

LESS engineering data are available in a usable form concerning the lifting of oil than in any other branch of the oil industry. Records often prove of little use, for no property presents the same problems as another and each well has its own variable load which must be handled.

Fully 50 per cent of the total of $11,300,000,000 invested in the oil industry is in the machinery of production. For engines alone the production end is spending $30,000,000 annually.

Engaged in actual oil life there are about 150,000[2] engines of all types, and these are being augmented at the rate of 15,000 per year. Of a total of 2,205,000 horsepower being delivered by internal-combustion engines in the oil fields, approximately 80 per cent, or 1,780,000 horsepower, is being delivered by the single-cylinder horizontal-type gas engine. Diesel engines in the oil industry are delivering 252,250 horsepower, steam 178,750 horsepower, and other internal-combustion engines of multicylinder type 372,820 horsepower.

The Single-Cylinder Horizontal-Type Gas Engine

The single-cylinder horizontal-type gas engine has been particularly adaptable to the oil fields because of its ruggedness, simplicity, flexibility of operation, compactness, and because it uses a fuel which is produced within easy access of the base of operations and does not necessitate the power plant upon which the operation of the steam engine or the electric motor is absolutely dependent.

The vertical engine has not won a place in the oil field so far as production methods are concerned. In the pipe-line transportation of oil multicylinder gas and Diesel engines have an established position. The inaccessibility of the vertical engine to field repair and maintenance has been the largest factor against its more general adoption.

The fundamental principles of engineering and thermodynamics concerning the gas engine have not changed materially in regard to the single-cylinder horizontal-type gas engine. However, the manufacturers of these engines have kept well abreast of the times in the use of the best available materials.

[1] Joseph Reid Gas Engine Company.

[2] From survey prepared by *Oil Field Engineering*. The figures following are computed from this survey.

Contributed by the Oil and Gas Power Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of the authors, and not those of the Society.

The Four-Stroke-Cycle Engine

The four-stroke-cycle engine still operates on the later principles adopted by Otto. It has, however, been necessary to sacrifice some of the high fuel economy of the older engines to make for a more accessible engine, with ease of operation and upkeep in the field. This decrease of thermal efficiency is due in part to the lowering of compression pressures and the position of the inlet and exhaust valves. Because there is a wide variation in the B.t.u. value of the gas that may be employed in an engine, it has been advisable to keep the compression pressures within such a range as will give a safe compression pressure even with a rich gas. Yet the engine must also be able to deliver a maximum of horsepower with a gas as low as 500 B.t.u. The high range of B.t.u. value rarely exceeds 1500. These values apply to natural gas. What has been stated above concerning the relation of fuel values and thermal efficiency in relation to compression pressures stands equally true for the two-stroke-cycle.

However, to revert to the four-stroke-cycle and the position of the valves, on the four-stroke-cycle single-cylinder horizontal-type gas engines which have an enclosed bedplate it has been necessary to have a separate combustion head so that the piston might be removed readily for inspection and repair. In order to accomplish such removal with a minimum of labor it has been desirable to keep the valve passages within the cylinder proper. Due to the arrangement of the stud holes for the combustion head the valve passage may form a small pocket which tends to lessen compression, and unless great care is used in design there is a liability to dilution of the fresh charge by pocketed exhaust gases. In cylinders of 12 in. in diameter and above, this is more easily taken care of as there is ample room for the bolt circle of the studs, thus allowing a minimum valve passage into the cylinder space.

One class of engines which does not have an enclosed bedplate nor a removable combustion chamber is operating at a thermal efficiency varying from 25 to 28. This particular class is using a valve conceived by Mr. S. B. Daugherty which is worthy of description. The governor acts upon a gas and air valve which admits the correct proportions of air and gas into the main inlet valve. This valve is so constructed that the gas is admitted to the air through slender orifices in copper tuyeres which are inserted in the gas passage of the valve case. This system gives a homogeneous mixture, and engines equipped with this type of valve are delivering the best thermal results relative to the single-cylinder horizontal-type engine of which the author knows.

The Two-Stroke-Cycle Engine

The two-stroke-cycle gas engine has probably met with more radical change of design than the four-stroke-cycle.

The two-stroke-cycle was devised by Clerk in England, where he built his first successful engine in 1878. In order to obtain an impulse every revolution he used an auxiliary cylinder which forced the charge into the motor cylinder. Scavenging was accomplished through ports as is common in the two-cycle engines of the present day. In the first engine he tried to force the charge into the motor cylinder at the pressure of compression. This was found to be a useless expenditure of energy, and in a later engine the pumping cylinder operated at a pressure sufficient only to

force it into the motor cylinder. The pump cylinder in the later engine was actuated by means of a wristpin inserted in the flywheel. Clerk, however, was never entirely successful in governing his engine, and it is of interest to note in one of his reports that his engine actually made 300 revolutions without a miss or backfire.

The first gas engine successfully applied to oil field uses was built at Oil City, Pennsylvania, in 1893 and put to work in the adjacent oil fields. Since that time the gas engine has been a fundamental factor in the production of oil.

This engine followed the design of Clerk, but was much more simple in design and in operation. It was also successfully governed, and positive ignition was obtained by a hot tube.

The immediate success of this engine and the continued demand for it gave the two-stroke-cycle engine a firm and lasting grip on the oil industry. Other American manufacturers entered the field using a modified European design which accomplished the function of the pumping cylinder in the crankcase rather than the use of the extra cylinder. Present practice has modified this, and a stuffing box is inserted between the crosshead guides and the joint of the cylinder and bed at a point best suited to the design. The working stroke of the piston thus serves also as a pumping stroke on the ingoing charge and forces it into the cylinder through ports above the exhaust ports.

The thermal economy of this engine as compared to the pump-cylinder type is not as high. It is the author's opinion that a pumping cylinder gives a cleaner charge, and is more positive in its injection, while compression-case injection is quite apt to inject the charge into the cylinder still retaining some of the exhaust gases.

However, the compression case style of engine has much to merit it as the most popular type of engine, and it is most widely used at the present time. Its design permits it to be entirely enclosed, thus preventing loss of oil and the entrance of foreign abrasive matter. The combustion head is easily removed and the piston withdrawn, as in the four-stroke-cycle engine, for inspection and repair. Journal bearings, crankpin, and crosshead guides and pin may be splash-oiled, thus eliminating hand or mechanical oiling devices.

In both the two- and the four-stroke-cycle engines the ratio between bore and stroke is somewhat less, following the general trend of automobile practice. Bearing sizes have materially increased due to the heavy loads that they must sustain. The tendency toward the large-diameter short-length bearing is becoming more pronounced, as there is less tendency for bend in this type and an increase in the projected bearing surface of such a bearing. Roller bearings are coming into use, but it cannot be stated that they have become generally adopted. This is not due to any mechanical obstacle, but the demand for this type of equipment has not yet reached the stage where it has warranted change of design entirely profitable to the manufacturer.

In the past five years there has been an increasing demand for a single-cylinder horizontal two-stroke-cycle engine which would run at speeds ranging from 180 to 450 r.p.m. without knocking or backfire. Formerly a speed of about 250 r.p.m. was the limit in oil-field work, and the new demands for quietness caused research into the mechanics of the rotating and reciprocating members of the engines to determine how these knocks could be eliminated at the high speeds of the horizontal engine.

One manufacturer lightened these members 300 lb. and eliminated a knock that had occurred at 257 r.p.m., and there was no return of the knock until a speed approximating 380 had been reached. Due to the fact that the parts had been lightened to the point of safe operating limits a force-feed oiling system was developed upon the recommendation of L. H. Morrison. This system supplies oil at 50 lb. pressure to the journal, crankpin, and crosshead-pin bearings, and no knock has been detected at speeds a little in excess of 500 r.p.m.

Application of Single-Cylinder Horizontal-Type Gas Engine

The single-cylinder horizontal-type gas engine is applied to the oil-field production division in several ways, namely:

(*a*) Drilling
(*b*) Swabbing
(*c*) Pumping an individual well
(*d*) To drive a pumping power
(*e*) To drive compressors for air lift and repressuring of oil sands
(*f*) To drive water pumps for water-flood processes.

Wherever methods (*e*) and (*f*) are employed, method (*d*) must also be used.

Because of its range of speed and extreme flexibility the two-stroke-cycle engine is used almost exclusively on methods (*a*), (*b*), and (*c*). Method (*d*) also largely employs the two-stroke-cycle engine, but there has been a decided trend toward the four-stroke-cycle in the last few years.

Drilling by the cable tool or percussion system necessitates a range of speed and a variation of power that is found in the two-stroke-cycle engine. During the actual drilling operation, where it is only necessary to impart an oscillating motion to the walking beam, the engine is run at a speed of from 150 to 180 r.p.m., depending upon the horsepower required. When the hole has been drilled the additional depth allowed it by the temper screw (about 8 ft.) the walking beam is disengaged and the bullwheel shaft, which acts as a hoist drum, is brought into use to lift the tools from the hole. The engine is at once speeded up to over 450 r.p.m., and the tools are pulled from the hole. The bailer or sand pump is then let into the well, and when it has become filled with the detritus from the drilling the engine is again thrown wide open and the bailer is pulled up. Thus there is demand for speed range and at the same time an increasing power range with as near a constant torque as can be maintained at the higher speeds. When it is considered that the entire system of drilling tools must be lifted from a depth that steadily increases to 3000 or 4000 ft., and may contain water for much of its depth, it is at once obvious that tremendous strains are imposed upon the engine and that it is vital that there be no stalling with the load.

Swabbing Method

Method (*b*), or swabbing, is employed when a well ceases to flow or where the production is too great for the usual pumping unit.

The swab is lowered and the fluid passes through a check valve and emerges above the swab. The power is then pulled from the hole. Damage has been done by inserting the swab too far into the fluid and then attempting to withdraw it suddenly. Derricks are sometimes pulled down or other equipment damaged. An unloader now automatically releases a too heavy load.

Swabbing often continues over long periods with the engine racing at full speed. Engines rated at 45 b.hp. at 180 r.p.m. are being driven at 450 to 500 and delivering 90 b.hp. to handle these loads.

When the swabbing recovery becomes no longer profitable, method (*c*), or pumping, is used. The engine drives the walking beam at 20 to 35 strokes per minute, the length of the stroke varying from 24 to 60 in. The bull wheel is maintained to pull the pumping equipment. Here again a variation of speed and power is necessary, and the two-stroke-cycle engine is the most flexible and applicable unit.

As the oil diminishes it no longer is profitable to pump with an

individual engine. Here the pumping power, or method (*d*), comes into use as a vital piece of machinery. It will be described farther on. This unit is driven either by the two- or four-cycle engine, but is most satisfactorily operated by the four-cycle engine.

Repressuring the Oil Sands

Eastern oil fields have shown a constantly diminishing production for many years. When it finally was realized that gas was the carrying agent of oil through the sand, operators forced it back into the oil sands at the necessary pressures for penetration. Where there was not enough gas, compressed air was used.

Compression, method (*e*), is accomplished by the gas engine driving a standard compressor either directly or by belt. The air or gas is forced at pressures from 60 to over 200 lb. Usually several months, and in some cases several years, elapse before improvement in production is shown. It may amount to 500 per cent and will continue for considerable time.

The best practice as regards power for compressors requires a four-stroke-cycle engine. This type makes for steady running and a constant volume and pressure delivery of air.

Using Water Pumps

An important method used in depleted Eastern sands is the water-flood method (*f*). Water is introduced into four surrounding wells at pressures from 300 to 2000 lb. depending on the porosity of the oil stratum. This forces ahead of it the gas in considerable quantities and then the oil. This so-called five-spot system is now causing a production of 12,000 barrels of oil to $1^1/_2$ wells per acre.

The four-cycle engine is used in sizes from 25 to 100 hp. to drive water pumps for flooding. In both the air and water flood 24-hour service is imperative. As the sands become impregnated with air and water, the loads increase and greater demands come upon the engine.

The Pumping Power

As previously stated the oil recovered by methods (*e*) and (*f*) is dependent on method (*d*) to raise it from the hole. The power consists of a gear or wheel supported by a vertical shaft and revolving in a horizontal plane. The hub is attached to two eccentrics, in usual practice, which act as cranks, also revolving horizontally, thus imparting the reciprocating motion necessary. The bandwheel type of power will be dealt with because of its widening use and because the demand for larger diameters of bandwheel presents a greater engineering problem. The 24-ft. wheel is the largest size in popular use.

A bandwheel power consists of a base and an upright shaft. Formerly it was the practice to mount on the shaft the bronzed bushed eccentrics and the wheel hub. The rim of the bandwheel was held in place by spokes running to the hub. Stiffening members, driver angles, or channels impart the motion of the wheel to the center of the power. The weight of the hub and eccentrics or the rotating parts is borne by a bearing plate or disk in the base. Upon this plate is exerted a force of about 40 lb. per sq. in. of projected area. In one example of a bushed power there is a total projected area of 461 sq. in. Upon this a 40-hp. engine will exert a pressure of 2880 lb. per sq. in. of projected area.

The demand for a power to handle deep wells with a heavy fluid load and a long stroke caused considerable change in power design. The adoption of roller bearings permitted more massive parts.

Progress of Design

In the progress of design, the shaft, which is treated as a beam supported at one end, has retained the same relative function as previous practice had assigned to it. This is also true of the base. The sleeve which is slipped over the shaft relieves the shaft of much of the strain. The sleeve itself does not make a fit to the shaft, but a receptacle in the base of the sleeve contains a roller bearing. The outer race of this roller bearing makes a light driving fit to the sleeve. The inner race is fitted to the shaft by heating the race to a temperature 240 deg. fahr. in raw linseed oil, and then shrinking it on the shaft at the base. The cup of the upper roller bearing is contained in the wheel hub; the cone, which is a light drive fit to the shaft, is pushed into place by an adjusting nut. The eccentrics are placed below the wheel hub, making a close fit to the sleeve. Slip rings over the eccentrics impart a reciprocating motion to the rod lines. The eccentrics are placed at an angle of 180 deg. to each other.

To revert to the strains upon the roller bearings, there are two forces exerted, the radial load and the thrust load. Both the upper and the lower bearing share the radial load exerted by the force of the prime mover and the action of the wells and surface equipment. When the power is motionless, there is only the thrust load, caused by the actual weight of the power, exerted on the lower roller bearing. When the power is in motion, both bearings take the radial load, and the thrust load becomes negligible if the strain rods are rightly placed, and the wells are balanced.

Eccentric Rings

Eccentric rings must be built to withstand the radial force exerted by the pull of equipment, and it must be heavy enough to care for the intense strain of starting. One test made of an eccentric ring with an inside diameter of 39 in. showed an elongation through the diameter of 0.010 in., which amounts to 0.00023 in. elongation per inch. In this case a load of 20,160 lb. was suspended from one of the clevis-pin holes.

The wheel itself is subject only to the force brought upon it by the belt transmitting the horsepower. This force tends to collapse the wheel, and an 18-ft. bandwheel must sustain a load of 10,900 lb. under ordinary oil-country belting conditions.

Principal Forces Exerted

The principal forces exerted on the power are the force of the prime mover exerted through the wheel and hub to drive the power, and the force exerted by the wells and equipment which may be expressed as a drag upon the rings and eccentrics.

The force exerted by the prime mover is constant for a given speed, but its effective work is dependent upon its application to the bandwheel. Bandwheels are constructed in sizes suitable to requirements, and the ratio may be kept between the prime mover and the stroke of the wells such that pulley sizes will permit a belt of proper width and belt speed to be used. Oil-field belt is rated as delivering 1 hp. per 1 in. width at a belt speed of 350 ft. per min.

Horsepower Necessary

Horsepower necessary on a basis of delivery from the prime mover should give the engineer a starting point from which to figure his requirements. The fluid weight may be easily computed. The lift is also a known quantity, as is the number of strokes per minute. This, however, is not the ultimate horsepower necessary when all factors are taken into account.

An Axelson hydraulic tester showed a starting load of 19,200 lb. on a well 3080 ft. deep, having a 54-in. stroke 20 strokes per minute. For the 3-in. tubing used the known fluid load is about 2570 lb., requiring 21 hp. to lift it. The remaining 11,490 lb. is the dead lift of inertia.

It would require 31 hp. to overcome the inertia or 52 hp. simply

to start the well. The surface conditions raise the requirements to 100 hp. for the lease of 10 wells.

An Absorption Unit

The power is unquestionably an absorption unit for a complicated system of forces. Its function has been performed when it has negated these forces in relation to each other, has overcome the primary inertia, and has established regular reciprocating motion to the rod lines.

Such a function calls into play loads which bring tremendous pressures on the bearing surface of the ring, eccentric, and shaft of the power. Should there be no balance of forces there is a concentration of load on a limited area of bearing which is destined to cause undue friction, binding, and faulty lubrication which tends to the ultimate destruction of the power.

The actual mechanical forces, other than the prime mover, acting on the power might be illustrated by the simple self-propelled merry-go-round.

A blunt-nosed pole supports a cap, from which is suspended a ring. Improper balance will cause the ring to swing in against the pole. Imagine the ring to be eccentric, and also imagine a part similar to an eccentric inserted within the ring. Any force acting upon the ring must be transmitted to the eccentric. Any off-balance forces the ring against the eccentric.

Balance in Equipment

Now consider the ring of the merry-go-round apparatus balanced but motionless. It will require considerable force to set it in motion. This corresponds to the kick imparted to the power by the prime mover. Motion thus given to the merry-go-round is maintained by a slight motion of the bodies in balance, and at some point in the revolution of the wheel there is apparent slack. It is apparent that any outside unequalized force on the ring causes unbalance. The same forces illustrated are those brought to play in the power. A load on one side of one ring will not carry an initial starting load which has a great weight of fluid in addition to the deadweight of the surface and well equipment. Balance in equipment is very necessary because of the variation of fluid load. The fluid load is taken care of by the prime mover, which must care for this load even after the power is in motion.

Powers are designed with the idea of relief from the heavy strains at some point in their revolution. This is shown in the use of the two eccentrics, upper and lower, and in their position of 180 deg. to each other. Without this relief which exists in the form of balance, the problem of correct lubrication would be difficult. This relief is comparable to the slack in the merry-go-round arrangement.

The foregoing discussion speaks much of balance and unbalance, and somewhat of the prime mover. Many inquiries come to the manufacturer as to what horsepower is necessary for a bandwheel power job. A manufacturer can give the horsepower needed to lift a certain amount of fluid in a certain size of working barrel at a certain stroke and speed. Table 1 gives these data from which may be computed the power necessary for various depths under the given conditions. These take account of nothing but direct lift, and a clear knowledge of the other variables working against the power must be presented if a buyer is to receive the most economical and satisfactory equipment. These variable factors are the very factors determining the balance of the wheel. The factors which must be considered are the following ones:

TABLE 1 HORSEPOWER REQUIRED PER 1000 FEET FOR ONE WELL USING 2-INCH TUBING, 1¾-INCH BARREL

Length of stroke (in.)	Stroke per minute: 8	10	12	14	16	18	20	22	24	26	28	30
12	0.25	0.31	0.37	0.44	0.50	0.56	0.64	0.69	0.76	0.82	0.88	0.95
14	0.29	0.36	0.43	0.51	0.58	0.65	0.74	0.80	0.88	0.95	1.02	1.10
16	0.33	0.42	0.50	0.59	0.67	0.75	0.84	0.92	1.01	1.09	1.17	1.26
18	0.37	0.47	0.56	0.66	0.75	0.84	0.95	1.03	1.13	1.23	1.32	1.42
20	0.42	0.52	0.67	0.73	0.84	0.94	1.05	1.15	1.26	1.37	1.47	1.58
22	0.46	0.58	0.69	0.81	0.92	1.03	1.16	1.27	1.39	1.51	1.62	1.74
24	0.50	0.63	0.75	0.88	1.01	1.12	1.26	1.38	1.51	1.65	1.76	1.90
26	0.54	0.68	0.82	0.95	1.09	1.22	1.37	1.50	1.64	1.79	1.91	2.06
28	0.59	0.73	0.88	1.09	1.17	1.31	1.47	1.62	1.76	1.92	2.06	2.22
30	0.63	0.79	0.94	1.10	1.26	1.41	1.58	1.73	1.89	2.06	2.21	2.38
32	0.67	0.84	1.01	1.17	1.35	1.50	1.68	1.85	2.02	2.20	2.36	2.54
34	0.71	0.89	1.07	1.24	1.44	1.59	1.79	1.97	2.14	2.34	2.50	2.70
36	0.76	0.95	1.13	1.32	1.52	1.69	1.89	2.08	2.27	2.48	2.65	2.86
38	0.80	1.00	1.20	1.39	1.61	1.78	1.99	2.20	2.39	2.62	2.80	3.02
40	0.84	1.05	1.26	1.46	1.69	1.88	2.10	2.32	2.52	2.76	2.95	3.18
42	0.88	1.11	1.33	1.54	1.77	1.97	2.20	2.43	2.65	2.89	3.10	3.33

2½-INCH TUBING, 2¼-INCH BARREL

Length of stroke (in.)	Stroke per minute: 8	10	12	14	16	18	20	22	24	26	28	30
12	0.41	0.52	0.63	0.75	0.84	0.94	1.04	1.14	1.25	1.36	1.46	1.56
14	0.48	0.61	0.73	0.87	0.98	1.09	1.21	1.33	1.46	1.58	1.70	1.82
16	0.55	0.70	0.83	0.99	1.12	1.25	1.38	1.52	1.67	1.81	1.95	2.08
18	0.62	0.79	0.93	1.11	1.26	1.40	1.55	1.71	1.88	2.03	2.19	2.34
20	0.69	0.88	1.03	1.23	1.40	1.56	1.73	1.90	2.09	2.26	2.44	2.60
22	0.76	0.96	1.13	1.35	1.54	1.72	1.90	2.09	2.30	2.49	2.68	2.87
24	0.83	1.06	1.23	1.47	1.68	1.87	2.07	2.28	2.51	2.71	2.92	3.13
26	0.90	1.15	1.33	1.59	1.82	2.03	2.24	2.47	2.72	2.94	3.16	3.39
28	0.97	1.24	1.43	1.71	1.96	2.18	2.42	2.66	2.93	3.17	3.41	3.65
30	1.04	1.33	1.53	1.83	2.10	2.34	2.59	2.85	3.14	3.39	3.65	3.98
32	1.11	1.42	1.63	1.95	2.24	2.50	2.76	3.05	3.35	3.62	3.89	4.18
34	1.18	1.51	1.73	2.07	2.38	2.65	2.93	3.24	3.56	3.84	4.13	4.44
36	1.25	1.60	1.83	2.19	2.52	2.81	3.11	3.43	3.76	4.07	4.38	4.70
38	1.32	1.69	1.93	2.31	2.66	2.96	3.28	3.62	3.97	4.29	4.62	4.96
40	1.39	1.78	2.03	2.43	2.80	3.12	3.45	3.81	4.18	4.52	4.86	5.22
42	1.46	1.87	2.13	2.55	2.94	3.28	3.62	4.00	4.39	4.75	5.10	5.49

3-INCH TUBING, 2¾-INCH BARREL

Length of stroke (in.)	Stroke per minute: 8	10	12	14	16	18	20	22	24	26	28	30
12	0.62	0.78	0.94	1.09	1.25	1.41	1.56	1.72	1.88	2.02	2.26	2.34
14	0.73	0.91	1.09	1.27	1.46	1.64	1.79	2.00	2.18	2.35	2.62	2.73
16	0.83	1.04	1.25	1.45	1.67	1.87	2.03	2.29	2.49	2.69	2.98	3.12
18	0.94	1.17	1.41	1.63	1.88	2.11	2.26	2.57	2.80	3.03	3.34	3.51
20	1.04	1.30	1.56	1.81	2.09	2.34	2.50	2.85	3.11	3.37	3.70	3.90
22	1.15	1.43	1.72	2.00	2.30	2.58	2.73	3.14	3.42	3.71	4.06	4.30
24	1.25	1.56	1.88	2.18	2.51	2.81	2.97	3.42	3.72	4.05	4.42	4.69
26	1.36	1.69	2.04	2.36	2.72	3.04	3.20	3.71	4.03	4.39	4.78	5.08
28	1.46	1.82	2.19	2.54	2.93	3.28	3.44	3.99	4.34	4.72	5.14	5.47
30	1.57	1.95	2.35	2.73	3.14	3.51	3.67	4.28	4.65	5.06	5.50	5.86
32	1.67	2.08	2.51	2.91	3.35	3.75	3.91	4.56	4.96	5.40	5.86	6.26
34	1.78	2.21	2.67	3.09	3.56	3.98	4.14	4.85	5.27	5.74	6.22	6.65
36	1.88	2.34	2.82	3.27	3.77	4.21	4.38	5.13	5.57	6.08	6.58	7.04
38	1.99	2.47	2.98	3.45	3.98	4.45	4.61	5.42	5.88	6.42	6.94	7.43
40	2.09	2.60	3.14	3.64	4.19	4.68	4.85	5.70	6.19	6.76	7.30	7.82
42	2.20	2.73	3.29	3.82	4.40	4.92	5.08	5.99	6.50	7.10	7.66	8.22

Surface Conditions

Ground contour
Necessity for hold-ups, hold-downs, and swings
Distance from well to power friction
Temperature changes
Nature of rod line
Type of jack
Length of stroke
Strokes per minute
Location of future wells
Will present equipment meet future demands?

Well Conditions

Depth of wells
Strength of sucker rods
Fluid conditions
Nature of fluid
Fluid weight equalized
Straightness of hole
Future fluid conditions.

Surface Conditions

On a lease where the land is nearly level ideal conditions are

met for power installation. A minimum of friction is encountered, and no added strain is met in devices for acute change of direction. In land cut by ravines and gullies a system of hold-ups, hold-downs, and swings is requisite to give proper direction and tension to the rod lines. These must be laid out to produce a minimum of strain upon the power.

Balanced wells a mile from the power are efficiently pumped where the suspension of the rod lines is properly managed. Where rod lines are very long, compensation must be made in the stroke of the well due to temperature changes and stretch of the rod lines.

In order that there shall be a minimum loss of stroke due to the change of direction of forces in the pumping jack, it should be so designed that the rod line will keep a constant tension on it, otherwise jerky motion, loss of stroke, and consequent unbalance result.

Any attempt to move the load with a long, fast stroke requires more power than slower and less stroke. Stretch of sucker rods due to fluid load is another necessary factor to be considered.

Well Conditions

There has been no limit set as to the depth of wells handled by the bandwheel power. However, deep wells must be carefully balanced. Attention must be given to tubing and working barrel sizes so that they balance opposing wells. Also the opposing wells should be as nearly equidistant from the power as possible unless some form of mechanical balance is introduced.

Power requirement in respect to fluid loads, in its nature and quantity, gives the engineer the key to his figuring. Consideration, however, should be made of the prospect of the fluid load increasing. It is often the case that the heaviest demands come on a power when it has already handled heavy loads for a long time and may be in need of replacement by heavier equipment, especially where there is great increase in the amount of water in the well.

Proper balance is nearest attained when the weight of equipment on the descending well is so distributed that it will actually assist in lifting the load of the opposed well.

To gain maximum efficiency and be furnished the most suitable equipment the engineer must carefully lay out his power location, and present all the factors upon which economical and efficient power installation and use depends.

These powers are nearly all driven by the single-cylinder horizontal-type gas engine. The tendency to the four-stroke-cycle engine has become much more evident with the depletion of the gas supply; and because of its higher thermal economy, ruggedness, and steady power output it is being generally accepted over the two-stroke-cycle engine. Requirements vary from 25 to 100 hp. and are continuing to increase as wheels are made larger and wells go deeper.

Conclusion

There has been outlined the application of the single-cylinder horizontal-type gas engine to oil recovery methods. It predominates in the field as the most economical prime mover, the most accessible, and the most foolproof in the hands of the general run of operators.

Conservatively estimating that about one-seventh of the oil available has been recovered and that further recovery depends on the application of mechanical methods, it is apparent that a tremendous field of activity awaits the engineer.

Discussion

Edgar J. Kates.[3] In view of the author's interesting classification of the proper fields of application for two-stroke-cycle and four-stroke-cycle gas engines, it would be desirable for him to add some information on the relative costs of these two types of engines.

H. C. Dickinson.[4] In view of the remarks relative to the possible efficiency of oil-field pumping equipment, the writer wishes to say a few words for the comparatively simple and crude system which has been developed in the oil fields and is current practice at the present time.

Consider for a moment what the problem involves. There are several stations, anywhere from five to twenty, scattered over an area sometimes more than two miles in diameter, at each of which stations a small amount of power is required to drive a reciprocating pump. The problem which presents itself is to distribute such power as is needed to these various stations, and this must usually be done from a single central power station. Individual units are out of the question, both on account of the cost and labor of maintenance.

The system of power transmission which has been developed to meet this need consists of a single tension rod or wire running directly from the power station to each of the individual pumps. This rod is suspended on swinging supports and is subject only to longitudinal motion. Each individual rod is kept in tension, and the several stations are balanced to a certain extent against each other. It should be borne in mind also that these transmission members must be mounted over all sorts of territory, sometimes in such a way as to interfere as little as possible with cultivation.

If one considers the fundamental mechanics of this problem and recalls the various possible mechanical devices which would be adapted for this purpose, it seems almost inconceivable that any of the devices commonly used or available could accomplish the pumping operation with anything approaching the overall efficiency or at a price comparable with that of the present system. The power loss in the transmission mechanisms themselves is confined almost entirely to the imperfect elasticity of the tension members. The efficiency of the pumps and of the central driving mechanism might possibly be improved. The pump, however, is an age-old contrivance, and it is doubtful whether it could be greatly improved for the existing conditions.

One might, for instance, conceive of a pneumatic or hydraulic system, or of a belt or rope drive or shaft. It requires only the briefest consideration to realize that any one of these mechanisms would be vastly more expensive in first cost and in cost of upkeep, as well as vastly lower in efficiency than the present system.

When one considers also the fact that the installation operation and general maintenance of these pumping equipments are usually in the hands of operators with the slightest possible mechanical experience and most meager facilities, the comparative merit of the present crude pumping system becomes even more obvious.

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Joint Use of Diesel and Steam Engines to Balance Heat and Power

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This paper deals with the use of Diesel engines in steam-power plants supplying both heat and power, the purpose being to increase the efficiency of steam utilization. This is accomplished by reducing the amount of unused exhaust steam and results in lower over-all costs for power and heat. The meaning of "exhaust-use factor" is illustrated by simplified examples. Similar examples are used to show the effect of Diesel power on over-all thermal economy and upon over-all costs.



TO BALANCE heat and power means, for the purpose of this paper, to utilize most economically space-heating and process steam in providing by-product power. It applies to industrial power plants supplying low-pressure steam or hot water as well as power. It also applies to power plants serving large city buildings such as office and loft buildings, department stores, clubs, and hotels. In such buildings the heat and power requirements imposed by human needs for illumination, elevator service, ventilation, and space-heating are quite similar in character to the demands of an industrial establishment, and both may be studied in the same way.

Importance of the Heat-Balance Problem

Engineers have long been aware that, by suitably selecting the steam-power equipment in such plants, the relative consumption of steam for power and heat may be so adjusted that the optimum quantity of steam will be used doubly. Such effective utilization of steam, with due regard to the investment charges, will cut to a minimum the over-all cost of heat and power.

There are many plants where this desirable balance has never been achieved. There are still others where the balance that once existed has been destroyed by the march of progress. In many industrial and commercial establishments the demand for power is increasing more rapidly than that for heat. The ratio is changing because the general trend of industrial progress is toward the more efficient use of steam in heating and process work, thus reducing the quantity of steam per unit of product, while at the same time the growing use of machinery is steadily increasing the power required per unit of product. Similarly, in large buildings, such as department stores, heat demands have changed but little, while power requirements have grown rapidly on account of the introduction of high-speed elevators, escalators, and air-conditioning systems, as well as increased illumination.

If, at all times of the day and at all seasons of the year, the consumption of heating steam is sufficient to develop as a by-product, in an ordinary steam plant, all of the power needed, the heat balance may be considered perfect from a practical standpoint.

But such conditions are not frequent. Generally the heating steam is deficient for part or all of the time, and the problem of reducing the cost of the prime power then becomes complex. Many methods are available—high steam pressure, extraction turbines, public-utility interconnections, etc. The attention which engineers have been giving this subject is evidenced by the many excellent analyses that have been published,[2] and also by numerous recent installations of high-pressure equipment and extraction turbines.

However, in endeavoring to reduce the cost of the prime steam power, engineers have generally limited themselves to modifications in the steam plant itself and have disregarded the possible use of Diesel engines for supplementing ordinary steam equipment and improving the over-all economy. The Diesel engine claims attention "when, as, and if" its fuel cost per kilowatt-hour is less than that of a steam-power plant whose exhaust heat is being wasted. Whether the addition of Diesel power is a better solution than a major alteration in the steam-power plant itself depends upon so many variable conflicting factors that it can be decided only after careful engineering analysis of each individual case. The purpose of this paper is merely to show that the Diesel alternative deserves careful consideration along with the others.

Fond as the engineer is of the B.t.u., it must be recognized at the outset of any study involving the joint use of Diesel and steam engines that a thermal analysis alone will not have any practical meaning. This for the reason that there is a great difference in the monetary value of a B.t.u. in the form of boiler oil and a B.t.u. in the form of Diesel fuel, the latter being 25 to 75 per cent more expensive. A study of this sort must therefore be primarily economic with heat values always converted into dollar values.

Scope of the Paper

It is the intention to confine this paper strictly to the subject of improving the economy of a steam-power plant by the use of Diesel engines. It is obvious that steam-plant economy can be improved also in many other ways, but these methods are not within the scope of the paper, and neither are the many methods of altering the relations between power and heat requirements at points of utilization. The fact is that even the subject of using Diesel engines in steam plants is too broad for complete treatment in this paper. Consequently, only one type of steam plant will be considered in detail—a moderate pressure

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Presented at the Third National Oil and Gas Power Meeting, State College, Pa., June 12 to 14, 1930, of The American Society of Mechanical Engineers.

[2] "Balancing Heat and Power in Industrial Plants," *Trans. A.S.M.E.*, May–August, 1929, FSP-51-27. "Coordination of Industrial-Plant and Central-Station Power," *Trans. A.S.M.E.*, January–April, 1929, FSP-51-16. "Combinations of Power and Process That Reduce Costs," *Power*, August 27, 1929, p. 316. "Analyzing the Power-Purchase Problem," *Power*, May 18, 1926, p. 777. "Power From Process and Space-Heating Steam," paper read January, 1930, at Annual Meeting of American Society of Heating and Ventilating Engineers.

(150 lb. to 175 lb.) non-condensing plant with a seasonal variation in steam consumption for space-heating and process requirements. Such plants are sufficiently common to give the study practical value, and the principles derived from the one type of steam plant can readily be applied to others.

The purpose of the paper is to show the principles involved rather than to derive definite figures for specific cases. The principles cannot be demonstrated by working out in full detail various plant arrangements, as so many factors are included that the relative effect of each would be concealed in the final figures. Of course, that is the only way a specific case can be worked out in practice, but the number of different plant arrangements to be considered in a practical problem can be readily reduced by a clear grasp of the general principles. At a future time it is hoped to amplify the subject by records of the actual operating performance of joint Diesel and steam power plants.

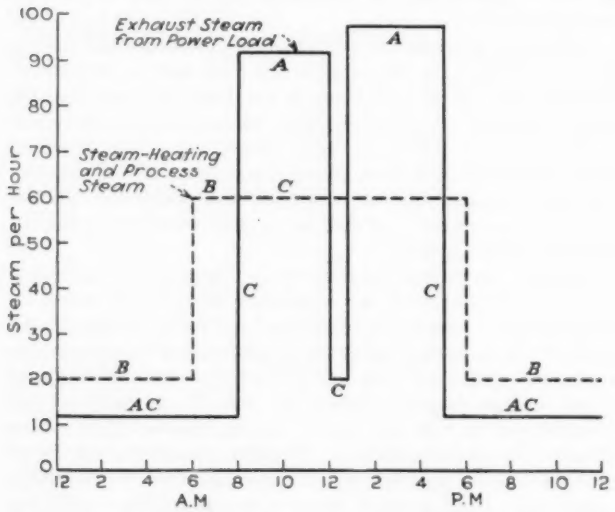


FIG. 1 STEAM LOAD CURVES, ILLUSTRATING USE OF FACTOR C/A

UTILIZATION OF EXHAUST STEAM

The economy of a joint Diesel and steam power plant is closely related to the ratios between the amount of steam doubly used for heat and power and the amounts used for either heat or power alone. These heat-use factors are illustrated by Fig. 1, which is an assumed chart of steam consumption for power and for heat (in an all-steam power plant) during a 24-hour period.

In this illustration A is the exhaust-steam output of the steam-power plant (which varies with the power load); B is the low-pressure steam consumed in space-heating and process, i.e., the "heat load;" and C is the engine exhaust-steam utilized (i.e., the portion of A that is also used to supply the heat load). Then:

- C/A = "exhaust-use factor" (shows proportion of steam power that is by-product)
- B/A = ratio of heat load to exhaust output
- C/B = proportion of heat load supplied by exhaust (remainder is heat to be supplied by reducing valve)
- B-C = heat supplied by reducing valve
- A-C = unused exhaust steam (corresponding to "prime" steam power).

Although it is the heat load B which makes possible the double use of steam for heat and power, the thermal analysis must start at the other end, i.e., the power load, inasmuch as an installed steam-power plant has a definite power capacity, and the real question is how much of the exhaust output of that power capacity can be utilized for heating. In other words, it is essential that the exhaust-use factor C/A should be large

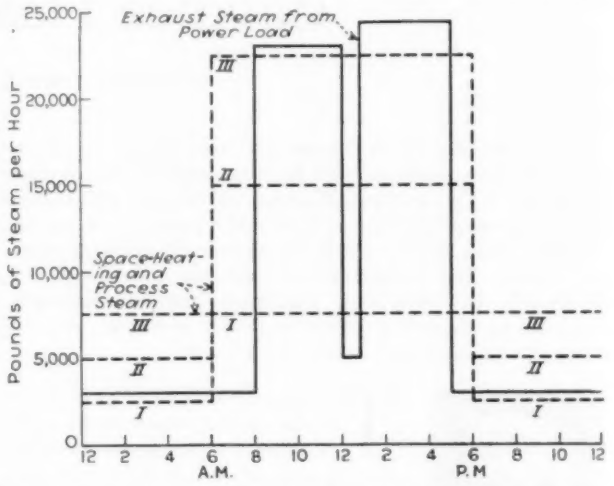


FIG. 2 COMPARISON OF POWER STEAM WITH VARYING REQUIREMENTS FOR HEATING STEAM

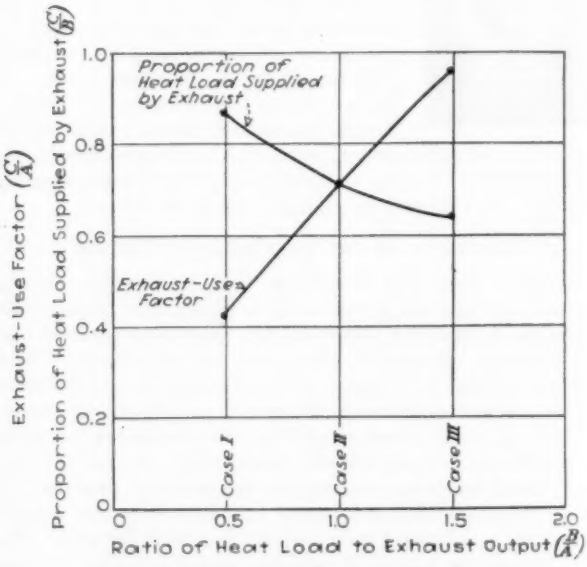


FIG. 3 RELATIONS OF HEAT-USE FACTORS

(to increase the proportion of by-product power), whereas it matters little what proportion of the heat load is supplied by the exhaust, i.e., C/B (since the remaining heat load must be supplied by the boilers in any case).

The exhaust-use factor is an extremely important consideration in studies of heat and power balance, and it must be correctly derived. Daily, monthly, or annual averages of heat and power consumption cannot be used directly in studies of private power plants unless the exhaust-use factors at all times are definitely known. This is made clear in Fig. 2, showing the assumed steam

TABLE 1 HEAT-USE FACTORS CORRESPONDING TO LOAD CURVES OF FIG. 2

	Symbol	Case I	Case II	Case III
Ratio of heat load to exhaust output...	B/A	0.50	1.00	1.50
Exhaust-use factor	C/A	0.43	0.71	0.95
Proportion of heat load supplied by exhaust	C/B	0.87	0.71	0.64
Unused exhaust, 1000 lb. per 24 hr.	A-C	136	70	10

consumption for power and heat over a 24-hour period in an all-steam power plant having the same power curve for each day of the year, but variable space-heating and process steam requirements as follows:

I Heating steam per day = 50 per cent of power-exhaust steam per day.

II Heating steam per day = 100 per cent of power-exhaust steam per day.

III Heating steam per day = 150 per cent of power-exhaust steam per day.

For the sake of clarity the graphs have been greatly simplified from practical conditions, but the general principles are not sacrificed. By "exhaust steam from power load" is understood the dry exhaust steam actually delivered to points of utilization—i.e., losses from drips and leakage having been deducted.

Table 1 and Fig. 3 show the heat-use factors computed from these graphs. It will be noted that the exhaust-use factor increases with the ratio of heat load to exhaust output; in other words, the percentage of by-product power increases as the heating load increases relative to the power load. But when the average heating load is equal to the power load (case II), the exhaust-use factor is only 71 per cent (instead of the ideal 100 per cent), and even when the average heating load is 50 per cent greater than the power load (case III), the engine exhaust is still not fully utilized. These simple relations have sometimes been overlooked, with the result that the amount of by-product power available has been overestimated.

Furthermore, it is evident that if the ratio of exhaust-steam utilization will be estimated too high if computed from *daily* averages, the error will be much worse if monthly, seasonal, or annual averages are used. Therefore when estimating future performance or analyzing past performance of actual plants, greatly detailed studies must be made. Such studies cannot be simplified by using averages for periods of a day or more, inasmuch as the amount of byproduct power produced is not dependent upon averages, but upon the simultaneous relations between the heat and power demands.[3]

In most cases it is necessary to obtain the characteristic heat- and power-load curves at different times of the year and also on different days of the week. Generally one must study the heat and power requirements for at least 50 days in the year.

A factory executive may remark that if power costs depend upon so many intricately related factors, any changes in manufacturing conditions that alter these factors will cause the power costs to deviate from the estimates. This is true, and is another reason why past predictions of costs have not always proved accurate. However, the cost variations will be much less in joint steam and Diesel plants than in all-steam plants, because the difference in cost between by-product power and prime power is much less in the combination plant.

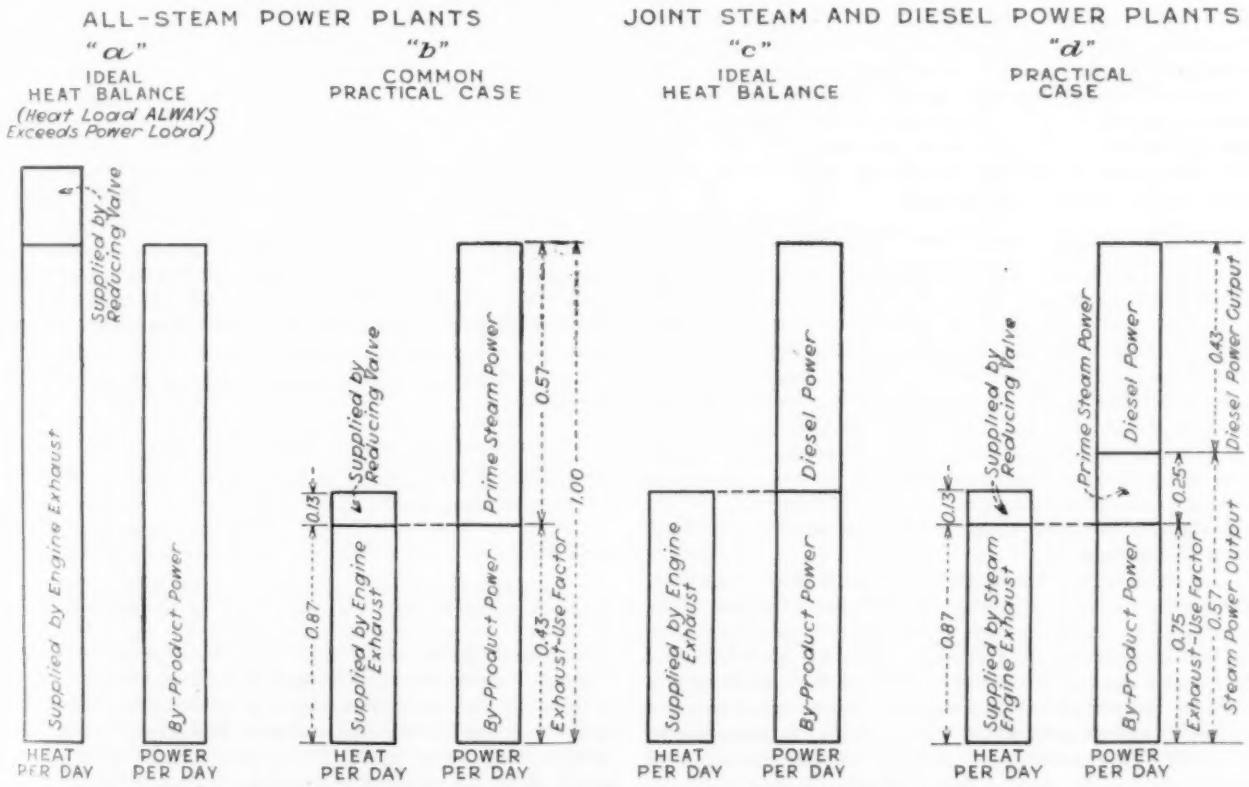


FIG. 4 THERMAL EFFECT OF ADDING DIESEL POWER TO A STEAM POWER PLANT

EFFECT OF DIESEL POWER ON OVER-ALL THERMAL ECONOMY

The addition of a Diesel engine to a steam-power plant may improve the over-all thermal economy in two ways: (a) by increasing the exhaust-use factor of the steam plant and (b) by replacing expensive "prime" steam power with less expensive Diesel power. This is illustrated by Fig. 4. Cases "*a*" and "*b*" refer to all-steam-power plants. Case "*a*" shows an ideal case based on the assumption that the heat load always exceeds the power load and that the exhaust steam is therefore fully

[3] The importance of coincidence in heat and power demands is diminished where heat-storage systems are employed, but even in such cases the heat demand can be controlled for only a comparatively short period.

utilized (exhaust-use factor 100 per cent). In this case all of the required power is produced as a by-product.

In "*b*" of Fig. 4 a common practical case is shown. The daily heat load is 50 per cent of the power load, i.e., B/A = 0.50 and the exhaust-use factor is 43 per cent. This results in 13 per cent of the heat load being supplied by reducing valves, while 57 per cent of the engine exhaust is wasted; i.e., 57 per cent of the power produced is "prime" steam power (and therefore costly).

Cases "*c*" and "*d*" of Fig. 4 represent the same heat and power requirements as "*b*," but part of the power is produced by a Diesel engine. Case "*c*" shows the ideal case where all of the heat load is supplied by the steam-engine exhaust, and, conversely, all of the steam-engine exhaust is utilized. The daily steam-power output is 50 per cent of the total power. In this case all of the steam produced is used doubly.

Case "*d*" shows the practical case for the joint Diesel and steam plant, corresponding to case "*b*" for the all-steam-power plant. The steam-power plant produces 57 per cent of the daily power output and the Diesel plant the remaining 43 per cent. The exhaust-use factor of the steam plant is increased to 75 per cent (from 43 per cent in "*b*"). By-product steam power still constitutes 43 per cent of the total power, the same as in "*b*." Case "*d*" corresponds to the daily steam-load curves of Fig. 5, to which further reference will be made.

Heat Recoverable From Diesel Engines

In the foregoing no account has been taken of the low-pressure steam or hot water that can be obtained by utilizing the heat rejected by the Diesel engine in its water jackets and exhaust gases. The recoverable heat per kilowatt hour of power output is much less than the heat discarded by a steam engine or turbine, being about 4500 B.t.u. per kw-hr. for a four-stroke cycle air-injection Diesel. Nevertheless it is of considerable value if it can be used. Over two-thirds of this recoverable heat is in the form of warm water discharged from the jackets. This costs nothing to recover and may often be used for boiler feed. Warm water is also useful in many factory processes or for faucet service in buildings.

The value of the Diesel exhaust heat is more debatable; whether its recovery is justified depends upon the cost of recovering it (including investment charges) and upon the cost of the heat it displaces. In all-Diesel plants with small heat load the exhaust heat may be highly valuable because it greatly simplifies the problem of heat supply. On the other hand, in combination steam and Diesel power plants such as are now being discussed, the availability of low-cost exhaust steam at all times minimizes the value of the Diesel-exhaust heat.

In any case, the heat recoverable from Diesel engines is too small in comparison with the heat demands in the sort of problems here under consideration to have any important influence upon the economic balance.

Cost Comparisons

Up to this point the analysis has been a thermal one. It now becomes necessary to give it practical meaning by considering the costs involved, rather than the B.t.u. The major cost variables are fuel costs and fixed charges; the minor ones are such items as attendance, maintenance, lubrication, supplies, ash removal, make-up water, and feedwater treatment. It is not implied that attendance is a minor item of power cost, but that the difference in attendance cost between steam and Diesel units is small. Furthermore, the various minor cost variables offset each other to such an extent that they do not appreciably affect the results of a preliminary study, and may therefore be ignored here.

It does not seem necessary in this paper to discuss the reliability and maintenance cost of Diesel engines. The intelligent steam operating engineer has no difficulty in learning to handle Diesel equipment. The records of modern Diesel plants show that their reliability is satisfactory and that their maintenance costs do not exceed those of a high-grade steam plant.

The relations of fuel cost and fixed charges will now be considered for combination plants consisting of uniflow steam engines operating noncondensing and Diesel engines without heat recovery. For the steam power plant the following conditions are assumed:

Boiler pressure, 165-lb. gage
Superheat, 100 deg. fahr.
Back pressure, 2-lb. gage
Boiler evaporation, 8 lb. steam per lb. coal
Engine economy, 30 lb. steam per kw-hr.
Heat delivered in steam, 1069 B.t.u. per lb.
Heat lost in engines, 4100 B.t.u. per kw-hr.
Price of coal, $6.25 per ton
Initial cost of steam engine plant, $80 per kw. capacity (500-kw. units)
Fixed charges, 12 per cent.

Then:

Fuel cost, by-product steam power	=	0.15 cents per kw-hr.
Fuel cost, prime steam power	=	1.17 cents per kw-hr.
Annual fixed charges	=	$9.60 per kw. capacity.

By-product steam power is understood to mean steam power the exhaust of which is fully utilized for heating, and which is therefore charged only with the heat actually abstracted in passing through the engines—i.e., 4100 B.t.u. per kw-hr. Prime steam power is steam power whose exhaust is not utilized.

For the Diesel part of the power plant the following conditions are assumed:

Fuel economy, 10 kw-hr. per gal.
Price of fuel, $0.05 per gal.
Initial cost of Diesel plant, $100 per kw.
Fixed charges, 12 per cent.

Then:

Fuel cost, Diesel power	=	0.50 cents per kw-hr.
Annual fixed charges	=	$12 per kw. capacity.

In estimating the initial cost of the Diesel power plant, it is planned to use combination steam and Diesel units consisting of the usual horizontal steam-engine generating unit with crankshaft extending beyond the outboard bearing and connected through a flexible coupling to a Diesel engine. The usual speeds of uniflow and four-valve steam engines match those of heavy-duty Diesel engines close enough to permit this common drive. In the summer time, when the steam ends of some of the combined units are not needed, the steam connecting rods can be disconnected. On the other hand, in the winter time, some of the Diesel engines can be disconnected from the generators by removing the flexible pins in the couplings. During the mild seasons when part steam and part Diesel power are required, both prime movers can be utilized on the common generator, the load being distributed between them according to the demand.

A combination steam and Diesel unit will effect a considerable saving in initial cost by reducing the installed generator capacity, the wiring from generator to switchboard, and the switchboard itself. It will also reduce foundation size and cost, inasmuch as the Diesel engine will have the benefit of the steam-engine foundation. Furthermore, there will be a considerable saving in space occupied. If the steam engine is of the vertical multicylinder type, the space saving will be still greater; in this case

TABLE 2 ESTIMATED INITIAL COST OF 750-HP. DIESEL-ENGINE INSTALLATION (To drive 500-kw. generator of steam unit)

Engine and erection	$37,500
Foundation (additional)	2,000
Fuel tank	1,000
Freight and carting	1,700
Piping	1,000
Pumps, air compressor, oil reclaimer, flexible coupling, etc.	1,500
Building space, additional	1,500
Contingencies	1,300
Engineering	2,500
Total	$50,000

the common generator might have its own shaft and bearings, with flexible couplings on both sides.

Table 2 is an estimate of the initial cost of a 750-hp. Diesel engine to drive a 500-kw. generator mounted on a steam-engine shaft. It will be noted that the additional cost of the Diesel end is $100 per kw.

Steam Power Plant Need Not Be Full Size

When a joint Diesel and steam power plant is planned there is no need to make the steam-power capacity sufficient to handle the entire power load. This holds true even when the winter heat load greatly exceeds the exhaust steam that such a full-size steam plant would produce. At first thought this statement seems illogical in view of the fact that with the part-size steam plant less by-product power can be produced and its place must be taken by the more expensive Diesel power. But though the fuel cost is thus increased, the fixed charges will be reduced to a greater extent. In other words, reducing the size of the steam power plant will avoid investment in steam plant used to generate by-product power for only a short time during the winter. This point is brought out in the following simplified examples.

Diesel Power Added to Full-Size Steam Plant (Case IV)

In case IV, Diesel power is added to a full-size steam plant. During the winter, the heat load is large, as per case III (Fig. 2), the daily heat consumption being 150 per cent of the exhaust-steam output. During this period the Diesel power is not used, and the steam units supply the same amount of by-product power as in case III, with only 10,000 lb. of unused exhaust steam per 24 hr.

During the summer, however, the heat load is less, as per case I (Fig. 2), where the daily heat consumption is only one-third that of case III. This is the time to use Diesel power, and in case IV it is assumed that sufficient Diesel-engine capacity is installed to reduce the maximum exhaust output from the steam plant from 24,500 lb. per hour to 12,500 lb. per hour. As will be shown later, this corresponds to a Diesel-plant capacity of 49 per cent of the total power demand. These conditions are illustrated in Fig. 5.

Here D is the reduction in exhaust output by substituting Diesel power.

Then $\frac{D}{A + D}$ = proportion of daily power output generated by Diesel power.

Table 3 shows the changes in heat-use factors accomplished by the joint use of Diesel power, case IV, as compared to the simple steam plant, case I. It should be noted that during the summer:

1 The exhaust use factor C/A is improved from 0.43 to 0.75.

2 The proportion of heat load supplied by exhaust steam C/B remains the same, viz., 0.87.

3 The unused exhaust steam is reduced from 136,000 lb. per day to 34,000 lb. per day.

These figures may be converted to dollar values by considering fuel costs and fixed charges as follows:

(*A*) *Fuel Cost, Summer.* The reduction in unused exhaust steam is 102,000 lb. per day. Dividing this by 29 (lb. of exhaust steam per kw-hr.), the reduction in steam-generated power is 3520 kw-hr. per day. Inasmuch as the saving in fuel cost per kilowatt hour between Diesel power and prime steam power is 0.67 cents per kw-hr., the saving in daily fuel cost is $23.60.

(*B*) *Fixed Charges.* In order to accomplish this saving the capacity of the Diesel installation must be 12,000 ÷ 29 = 414 kw. The steam-plant capacity, which in this case is sufficient to carry the entire power load, is 24,500 ÷ 29 = 845 kw. The additional fixed charges on account of the Diesel installation are 414 kw. × $100 × 12 per cent = $4970. Therefore, in order to offset these additional fixed charges, the Diesel power plant will have to operate under the summer-heat-load conditions (Fig. 5), for $4970 ÷ $23.60, or 210 days per year.

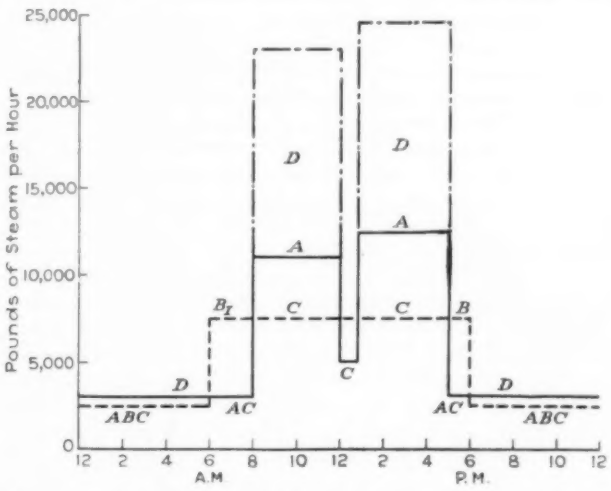


Fig. 5 Steam-Load Curves, Joint Diesel and Steam Plant, Summer Conditions

Diesel Power With Part-Size Steam Plant (Case V)

The effect of using Diesel power in conjunction with a part-size steam plant may now be investigated. This will be designated as case V, which is based upon the same Diesel capacity as in case IV (i.e., 414 kw.), but upon only 600 kw. of steam-power capacity (instead of 845 kw.). The total power demand remains, as before, 845 kw.

During the summer, the heat load being light, the Diesel plant is used at full power during the hours of maximum power load, and therefore the reduction in size of the steam plant does not affect its output. Consequently, the heat-use factor remains the same as for the previous case, as shown in Fig. 5 and in Table 3, case IV.

TABLE 3 EFFECT OF DIESEL POWER UPON HEAT-USE FACTORS IN JOINT POWER PLANTS

	All-steam power		Case IV		Case V	
Total power load	845		845		845	
Steam-power capacity	845		845		600	
Diesel-power capacity	0		414		414	
Season	Winter	Summer	Winter	Summer	Winter	Summer
Heat load, B	III	I	III	I	III	I
Ratio of heat load to exhaust output, B/A	1.50	0.50	1.50	0.87	1.90	0.87
Exhaust-use factor, C/A	0.96	0.43	0.96	0.75	1.00	0.75
Proportion of heat load supplied by exhaust, C/B	0.64	0.87	0.64	0.87	0.53	0.87
Reduction in exhaust output by substituting Diesel power, 1000 lb. per 24 hr., D	0	0	0	102	50.8	102
Proportion of daily power output generated by Diesel, $\frac{D}{A + D}$	0	0	0	0.43	0.21	0.43
Unused exhaust steam, 1000 lb. per 24 hr., A-C	10	136	10	34	0	34

In the winter, however, when the heat load is large (*B*-III) less by-product power is generated, and the thermal relations are as shown in Fig. 6. The reduction in by-product power occurs during the hours of maximum power demand; in this case between 8 and 12 a.m. and between 1 and 5 p.m. However, this thermal loss is partly compensated by the substitution of Diesel power for some prime steam power during the same hours. During these hours the full-size steam plant (845 kw.) would have exhausted 190,000 lb. of steam, of which 180,000 lb. would have been used for heating, while 10,000 lb. would have been wasted. In the present case, however, the 600-kw. steam plant exhausts during the same hours only 139,200 lb., all of which is used for heating. The reduction in by-product power is therefore 180,000 — 139,200 ÷ 29 = 1410 kw-hr., and the reduction in prime steam power is 10,000 ÷ 29 = 345 kw-hr.

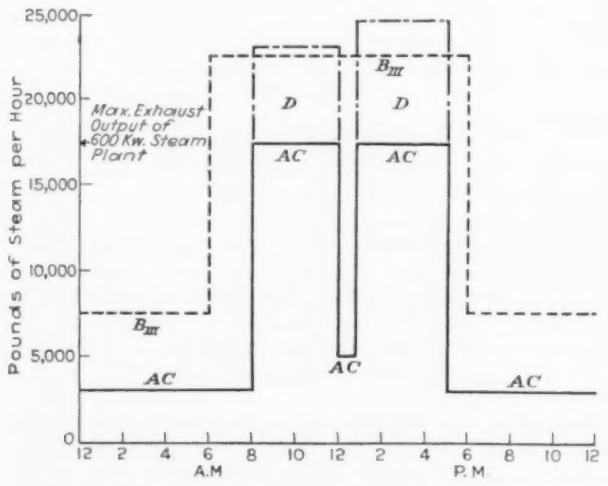


FIG. 6 STEAM-LOAD CURVES, DIESEL WITH PART-SIZE STEAM PLANT, WINTER CONDITIONS

Table 3 shows the heat-use factors corresponding to case V. It will be noted that the exhaust-use factor is raised to unity during the winter period; also that 21 per cent of the daily power output is generated by Diesel in the winter and 43 per cent in the summer.

Converting these thermal figures into costs give the following:

(*A*) *Fuel Cost, Winter.* Increased fuel cost by substituting Diesel power for by-product power = 1410 × 0.35 cents = $4.93. Decreased fuel cost by substituting Diesel power for prime steam power = 345 × 0.67 cents = $2.31. Net increase in fuel cost per winter day = $2.62.

Inspection of the load curves, Fig. 6, shows that the increase in fuel cost per winter day diminishes as the season becomes warmer. This is because the heat-load curve *B* drops in warmer weather, causing an all-steam-power plant to produce less by-product power and more prime power. Accordingly it is fair to assume for the present example that the reduced size of the steam plant will increase the fuel cost for the entire winter by 60 times the maximum daily increase, or $157.

(*B*) *Fuel Cost, Summer.* As already explained, the heat-use factors during the summer will be the same as in the previous case, and the fuel cost saving will also be identical, i.e., $23.60 per day.

(*C*) *Fixed Charges.* The additional fixed charges for case V as compared with the simple steam plant may be computed as follows:

Diesel installation, 414 kw. × $100 × 12 per cent...	$4970
Less reduction on steam installation, 245 kw. × $60 × 12 per cent.....	1760
Net additional fixed charges.....	$3210

TABLE 4 RESULTS OF TWO STUDIES FOR HEAT AND POWER SUPPLY

	Large loft building			Large department store		
Type of service.....						
Annual consumption of low-pressure steam.....	33,000,000 lb. per year			90,100,000 lb. per year		
Annual consumption of electricity.....	4,200,000 kw-hr. per year			7,576,000 kw-hr. per year		
Maximum demand for low-pressure steam..	25,000 lb. per hr.			47,500 lb. per hr.		
Maximum demand for electricity.....	1,500 kw.			2,419 kw.		
Type of plant considered.....	Purchased power	All-steam power	Joint steam and Diesel	Purchased power	All-steam power	Joint steam and Diesel
Steam power plant capacity.....	0	1700 kw.	1000 kw.	0	3000 kw.	1200 kw.
Diesel power plant capacity.....	0	0	700 kw.	0	0	1800 kw.
Annual overall cost including fixed charges[1].....	$127,500	$113,260	$105,460	$143,650	$123,600	$98,190

[1] Items common to all types of plants omitted.

In order to effect a net saving, the Diesel installation must more than offset by means of its summer fuel savings not only its additional fixed charges but also its additional winter fuel cost of $157; these items total $3367 per year. Therefore the Diesel power plant must operate under the summer conditions of Fig. 5 for 143 days per year.

PART-SIZE STEAM PLANT, WITH DIESEL POWER, IS JUSTIFIED

Comparing cases IV and V, it appears that the combination of Diesel power with a part-size steam plant accomplishes the following:

1 It substitutes Diesel power for expensive prime steam power during the hours of maximum power demand.

2 Even in the coldest weather, when the reduced size of the steam plant causes the greatest loss in by-product power, the increased daily fuel cost is only $2.62 as compared with a reduction of $23.60 in the daily fuel cost during warm weather.

3 The saving in warm-weather fuel cost will offset the extra fixed charges of the Diesel plus its extra winter fuel cost, if the small heat-load conditions exist for 143 days per year, as compared with 210 days in the case of the full-size steam plant with Diesel power.

Similar computations for an all-Diesel plant with the same power and heat conditions show that its annual cost would greatly exceed that of the combination plant. It is evident, therefore, that the part-size steam plant joined with Diesel power will produce the foregoing heat and power requirements at a lower annual cost than an all-steam plant, an all-Diesel plant, or a combination of Diesel power with a full-size steam plant.

RESERVE POWER

No attempt has been made here to decide the best total capacity for a practical power plant to meet the assumed load conditions, nor to determine the best relative proportions of Diesel and steam power, as these questions depend upon too many extraneous factors. One of these is the necessity for reserve power. The capacity of the combined steam and Diesel plant must, of course, exceed the maximum power demand. Generally it should exceed it by one spare unit, either steam or Diesel. There is certainly no need of planning to have both a steam and a Diesel spare unit, as one or the other, depending upon the season, will serve the purpose. In the cold season, when the steam plant is operating at full capacity, the Diesel equipment will provide reserve capacity. In the warm season, when the Diesel plant is in steady operation, the steam plant

will provide the necessary reserve. Some of the steam plant, in any event, will be running during the summer; consequently boilers and piping will be under pressure, and the remaining steam equipment can be put into service quickly.

In this connection it is well to keep in mind the unusual value of a Diesel engine for breakdown service. The Diesel unit, so far as the power end is concerned, is entirely independent of the steam plant; it therefore is available for use even if the entire steam plant is out of service. A spare steam-power unit, of course, does not enjoy this advantage.

Other Factors

Some other factors entering into a study of the joint use of Diesel and steam power deserve general comment, such as the following:

1 All of the preceding examples have been based upon noncondensing steam equipment. If it is feasible to install condensing equipment, the steam plant's fixed charges will be increased, but the fuel cost of prime steam power will be much lower, particularly in large plants; the resulting smaller differential with respect to Diesel-fuel cost will reduce the possible benefits of installing Diesel power.

2 In noncondensing steam plants using Diesel engines, good steam economy is not nearly as important as in all-steam plants, because less prime steam power is generated. Consequently, the steam plant may be simpler and less expensive. The four-valve steam engine deserves careful consideration in joint power-plant projects, as its lower initial cost may easily offset its slightly increased fuel consumption, under conditions of moderate steam pressure and atmospheric exhaust. To a smaller degree this also applies to the use of steam turbines.

3 In the numerical examples just computed, no account has been taken of the heat recoverable from the Diesel-engine water jacket and exhaust. This would obviously lead to still greater thermal economy, but would have to be offset against the additional fixed charges.

4 If the conditions are such that the power capacity of an existing steam plant must be increased, it is often easier to install a relatively compact Diesel unit rather than to enlarge the steam plant. If, as is frequently the case, the power load already exceeds the heat load, an increase in the steam power-plant capacity would necessitate installing not only additional steam engines but also boilers.

Plant Design

After the heat balance analyses have been concluded, the design of the joint power plant demands careful study. If new steam-power units are required, they must be carefully selected and due consideration be given to uniflow engines, four-valve engines, and turbines. The selection of the Diesel-power equipment involves questions of two-stroke cycle or four-stroke cycle, air injection or mechanical injection, running speed, governor control, and many others. The answers depend upon the kind of service required, the nature of the fuels available, and similar factors. In addition, the engineer must carefully consider the differences in power ratings of engines offered by various manufacturers and also their servicing facilities. He must design proper foundations, devise suitable water-supply arrangements, dispose of the exhaust gases without occasioning objections from noise or smoke or odor, and prevent the transmission of engine vibrations or noise to the surroundings. In many cases these are real engineering problems the successful solution of which depends upon the application of competent engineering skill and experience.

A number of refinements can be contrived for joint Diesel and steam power plants; for instance, the automatic division of load between the steam engines and the Diesels. This is desirable during periods when the heat load is less than the maximum exhaust-steam output and is fluctuating. At such times the best balance is obtained by loading the steam engines to the point where they will supply just enough exhaust steam to meet the heat requirements. In a direct-current installation this load distribution between steam and Diesel could be maintained automatically by controlling the voltage of a steam unit according to the exhaust back pressure. (This is predicated, of course, upon the steam unit having its own independent generator.)

Practical Examples

Several studies of heat and power balance involving the joint use of Diesel and steam engines have recently been made. Full details cannot be given, but the conclusions in two cases are presented in Table 4.

An actual application of Diesel engines in an existing steam power plant was recently made in the department store of R. H. Macy & Co., New York City. Here two 800-kw. Diesel generating units were installed in a steam power plant containing Corliss engines of 3350 kw. total capacity. The power load had grown faster than the heat demand because of the installation of escalators, electric elevators, additional lighting, and an air-conditioning system, so that even in the winter a large amount of the steam used for power generation had been wasted to the atmosphere. It is expected that the Diesel engines will go far to stop this waste. It is notable, too, that because of the compactness of modern Diesel engines sufficient space was found in a crowded engine room for two 800-kw. units in the space formerly occupied by pumps and tanks used for hydraulic elevators.

Another recent installation of a Diesel engine in conjunction with a steam power plant is that in the new Hotel New Yorker, in New York City. Here a 350-kw. Diesel unit was installed in conjunction with 2200 kw. of uniflow steam engines. In this case, however, the primary purpose of the Diesel installation was not to improve heat balance, but to provide breakdown protection. No matter what trouble may occur in the steam plant, the Diesel engine is always available for service, and even if the steam plant should be completely shut down, the Diesel engine has sufficient capacity to supply emergency power and light requirements. However, as far as the Diesel engine's effect upon the heat balance is concerned, its influence will be small, as the Diesel power is too small in comparison with the steam power.

Conclusion

It is hoped that this paper has brought out the following salient points:

1 Diesel engines can be effectively used in conjunction with certain types of steam power plants to produce power and heat at low over-all cost. Their utility consists in enabling the steam plant to produce the optimum quantity of by-product power from space-heating and process steam, while the Diesel units generate the remaining power at lower cost than a steam plant would.

2 In such joint steam and Diesel power plants the total plant capacity need not exceed that of a corresponding all-steam power plant. Despite some loss in thermal economy, the decreased investment results in lower over-all costs.

3 In any study of the use of power steam for heating purposes, the exhaust-use factor must be determined with the utmost care. Detailed analyses of power and heat requirements at all hours of the day and at all times of the year must be made; otherwise the amount of exhaust steam utilized may be greatly overestimated and erroneous conclusions be reached.

Discussion

S. B. Daugherty.[4] In one of the plants of the United States Steel Corporation, in their later installations of large gas engines, they provided (some six or seven years ago) for the installation of waste-heat boilers to recover the heat from exhaust gases. They had not at that time made the installations.

L. F. Burger.[5] The writer has in mind a plant that he installed in Pittsburgh some years ago. The party wanted only one generator, but wanted to operate it with two engines. It therefore was arranged to install the generator between the two engines. Sliding clutch couplings were mounted on both ends of the generator shaft and on one end of each engine's crankshaft. This installation was so arranged that one could operate the generator with both engines at the same time or either one of the engines could be cut off. This proved to be a very satisfactory installation. As the changes from one engine to the other engine could be made without throwing off the load on the generator, providing it was not greater than the capacity of one of the engines, this change could also be made without a noticeable flicker in the lights operated by current from the generator.

R. L. Sackett.[6] The paper emphasizes the importance of careful analysis of heat loads, peaks, and seasonal demands. Such papers serve to point out new fields where the Diesel engine may be used in parallel with other forms of prime movers.

Dr. Schweitzer, in his paper before the A.S.M.E. last December, directed attention to the possibility of peak loads in large steam-generating plants being carried with economy by oil engines.

There is still another field which has not yet received much attention before this Society. Hydroelectric plants are subject to fluctuations in output due to low flow and restricted storage. Steam has usually been employed as an auxiliary either to carry the peak or the base load, depending on conditions. Where the hydro power is a small factor on a large interconnected steam system, Diesel power may not be economy, but where a plant auxiliary is necessary, an analysis of the peak and base loads may show Diesel power to be advantageous. It is even possible that enlarging an existing hydro-steam plant may best be done by installing a Diesel unit.

Data of costs are now available, and careful analysis supported by sound judgment will show that Diesel power is an increasingly valuable base or auxiliary source of energy.

E. W. Hammond.[7] This paper clearly defines proper methods for the selection of Diesel and steam engines to balance heat and power. A similar study has recently been made at a refinery showing that Diesel engines had a wide field of application in this industry, even though refineries are large users of process steam as well as power.

After determining that Diesels are the economical prime movers, and the first study indicates a six-month operation is justified, a further survey should be made to compare costs of producing power with the steam units to include for these machines all fixed and operating charges. Since the first study assumes only six months' operation of the Diesel, all annual fixed charges have been applied against the Diesel. Additional operating time beyond six months for the Diesel requires only consideration of the operating charges, which may be lower than cost of producing power in the steam units, in which case these should be omitted and the heating or steam load carried on the boilers.

There is a proposed arrangement of a Diesel and a steam engine to drive a common generator with disconnecting couplings. This is a treacherous proposition, because with such an arrangement torsional vibrations are very likely to be present, and the danger of these is well known to every one. Likewise, there will be considerable difficulty in getting the governors of the steam engine and the Diesel engine set so that they will hold the same speed variation with changes of load.

Likewise it will be difficult to arrange for placing both units in service. The writer believes the better arrangement would be to have a separate generator direct-connected to each engine to eliminate all of these difficulties as well as to provide flexibility and continuity of power supply.

Edward J. Kunze.[8] Use of a steam accumulator as a heat exchanger in a Diesel system, as has been proposed, is not feasible. The steam accumulator is not intended to be used as a heat-recovery apparatus. It is designed to even the steam load over short periods of time, thus avoiding rapid fluctuations in pressure during such short periods.

Steam accumulators function by holding large quantities of water under a pressure and temperature considerably higher than those of the boilers they serve, so that on demand of a boiler some of this highly compressed water, passing through a reducing valve to the boiler, is flashed into steam at boiler pressure.

Obviously, high cost and large size, which are inherent in this system, eliminate the steam accumulator for use as a heat exchanger such as may be useful in a Diesel system.

Author's Closure

The recovery of Diesel-engine waste heat is not an important factor in joint steam and Diesel power plants, which are the subject of this paper. If such plants are designed for best dollar economy, the installed Diesel-engine capacity is less than the power load, and therefore steam engines are operating at all times. Thus cheap heat in the form of engine-exhaust steam is always available. (See Fig. 5 in the paper.)

During a few months of the year, when the heat load is a maximum, the steam-engine exhaust is inadequate (see Fig. 6), and the Diesel engine's heat would be useful. However, this condition of affairs is so brief that it would seldom pay to install Diesel exhaust-heat reclaimers, as their fixed charges and maintenance would generally exceed the cost of the same amount of live steam from the fuel-fired boilers. The situation here is quite different from the case of an all-Diesel power plant; in the latter the value of the exhaust heat is much greater and often fully justifies the installation of the heat exchangers necessary to reclaim it.

As for the warm water discharged from the Diesel-engine jackets, this low-temperature heat is available at no extra expense and should be utilized if it is at all possible. Furthermore, utilizing the jacket water not only saves heat but also water, and sometimes also eliminates a jacket-water recooling system.

Several of the discussors have cited objections to the suggested use of a combination generating unit consisting of a common generator driven by both a Diesel and a steam engine. The bugbear of torsional vibrations can be eliminated by mathematical analysis such as is now being successfully applied to many similar problems. The problem of governing is not difficult; the conditions for speed regulation of a steam engine and

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[5] International Harvester Company, Chicago, Ill.
[6] Dean of Engineering, Pennsylvania State College, State College, Pa. Mem. A.S.M.E.
[7] Worthington Pump and Machinery Corporation, Buffalo, N. Y.
[8] Associate Editor, *Power Plant Engineering*, Chicago, Ill. Mem. A.S.M.E.

a Diesel engine connected to a common shaft are practically the same as when separate steam-engine units and Diesel-engine units drive alternating-current generators in parallel, and this of course is quite common.

One is not compelled to resort to combination generating units in order to make practical applications of Diesel engines in steam-power plants. However, the attractive features of such a combination unit, i.e., reduced investment in foundation, generator, wiring, and switchboard, and a great saving in space, would seem to justify its development.

Research of the National Advisory Committee for Aeronautics on Aircraft Diesel Engines

By CARLTON KEMPER,[1] HAMPTON, VA.

The National Advisory Committee for Aeronautics has studied the theoretical performance possible with a Diesel engine operating upon a dual-combustion cycle. It has investigated the great number of factors which control the injection characteristics of fuel sprays, and coordinated and applied results from test information on fuel injection and combustion to the design of combustion chambers. Considerable progress has been made.



THE AIRCRAFT Diesel-engine research of the National Advisory Committee for Aeronautics is a part of a general program having for its object the investigation of the factors involved in improving the safety and economy of aircraft. The high-speed Diesel engine is attractive as a power plant for aircraft, because its use results in the following advantages: First, a reduction to a great extent of the fire hazard in aircraft; second, the elimination of radio interference without a system of ignition shielding; third, the reduction of fuel consumption; and fourth, the use at present of a cheap fuel. In its broadest aspect the problem of developing the aircraft Diesel engine is one of obtaining fundamental information on the characteristics of fuel sprays and air turbulence which affect combustion. Until the effect on the rate of combustion of such factors as drop size, rate of injection, spray dispersion and distribution, temperature, and air density and turbulence are known, it will be difficult to increase greatly the performance of the aircraft Diesel engine above the present values obtained with high-speed oil engines.

The research of the committee may be divided into three main parts. The first is a study of the theoretical performance possible of attainment with this type of engine operating upon a dual-combustion cycle. This work includes the determination of the effect on cycle, combustion, volumetric, mechanical, and cooling efficiencies of such factors as maximum cylinder pressure, compression ratio, and quantity of excess air. The only practical method for investigating these factors at the present time is to develop methods of calculating their theoretical effect. The results of this investigation serve as a guide to indicate the maximum performance possible of attainment. The second investigation is concerned primarily with the great number of factors which control the injection characteristics of fuel sprays. It is the demand in this investigation for more information on spray penetration and dispersion which produced the N.A.C.A. spray-photography equipment with which it is possible to take 25 consecutive pictures of a single spray at rates of from 2000 to 4000 pictures per second (reference 1). The third investigation has for its object the coordination and application of the results of all available test information on fuel injection and combustion to the design of combustion chambers which will give increased engine performance.

During the past year considerable progress has been made along the lines of obtaining information which will permit the successful prediction of the injection characteristics of a given design of fuel-injection system, and in increasing engine performance without appreciably increasing the maximum cylinder pressure. This paper will briefly review some of the results obtained in the various investigations conducted at the Langley Memorial Aeronautical Laboratory during the past year.

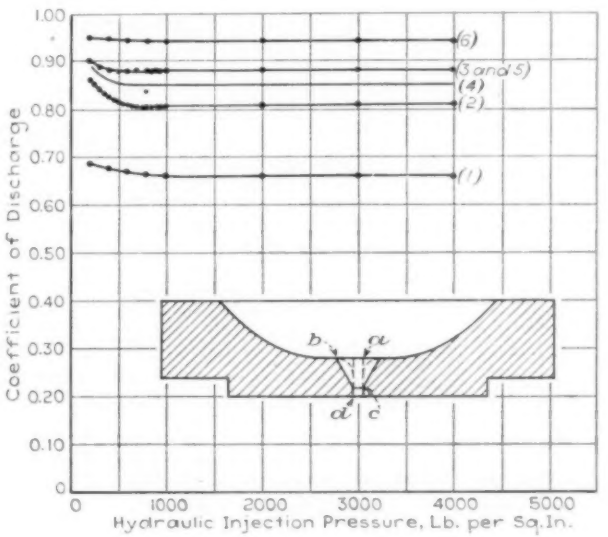


FIG. 1 EFFECT OF HYDRAULIC INJECTION PRESSURE ON COEFFICIENT OF DISCHARGE

(Curve (1) with leading edge *a* sharp; (2) with leading edge *a* rounded to approximately 1/16 in. radius; (3) leading edge rounded to 1/32 in. radius; (4) leading edge beveled 60 deg., corners *b*, *c*, and *d* sharp; (5) leading edge beveled 60 deg., corner *b* slightly rounded, *c* and *d* polished; (6) leading edge beveled 60 deg., corners *b*, *c*, and *d* slightly rounded. Orifice diameter 0.015 in., back pressure atmospheric.)

COEFFICIENT OF DISCHARGE INVESTIGATION

The present work of determining the coefficients of discharge for small-diameter orifices under high injection pressures is an extension of that undertaken by W. F. Joachim, and was conducted with the same equipment (reference 2). In this work the factors which have been investigated are the diameter and length-diameter ratio of the orifice, the injection pressure, and the shape of the approach to the orifice. Fig. 1 shows the effect of injection pressure and change in orifice approach on the coefficient of discharge for a 0.015-in. diameter orifice. At the start of the tests, the nozzle had sharp edges and gave a coefficient of discharge of about 0.65. The first change consisted in round-

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Presented at the Third National Oil and Gas Power Meeting, State College, Pa., June 12 to 14, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

ing the leading edge to approximately $^1/_{64}$-in. radius. This single alteration increased the coefficient from 0.65 to 0.80. The experiment was then tried of rounding the leading edge to approximately a $^1/_{32}$-in. radius. This change increased the coefficient to 0.88. The leading edge of the orifice was then beveled to 60 deg., leaving the edges sharp. A small decrease in the coefficient was obtained, but by slightly rounding the sharp edges *b*, *c*, and *d*, the coefficient was increased to 0.94. This represents an increase of 42 per cent in the value of the coefficient obtained by changing the shape of the orifice approach and in rounding the edges of the orifice. In this series of tests the orifice length-diameter ratio has been changed, and might be thought to have some effect on the coefficient of discharge. The curve

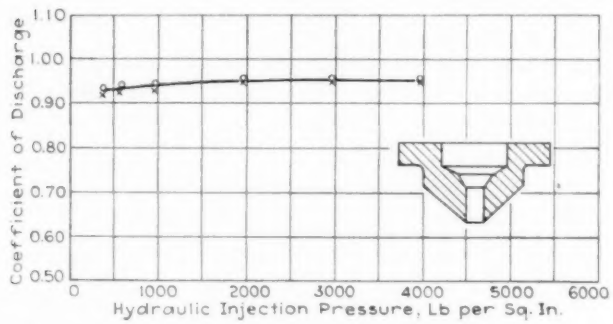


FIG. 2 EFFECT OF HYDRAULIC IGNITION PRESSURE ON COEFFICIENT OF DISCHARGE

(Orifice diameter, 0.014 in.; length-diameter ratio, 1, 2, and 3; back air pressure, atmospheric.)

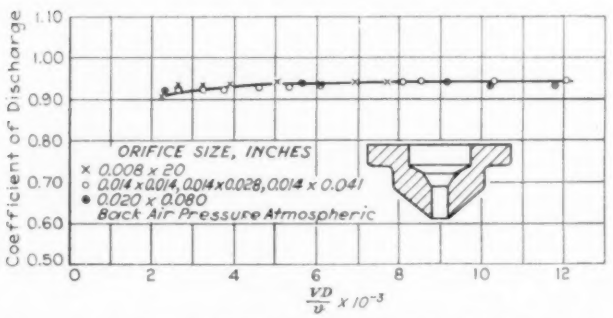


FIG. 3 VARIATION OF COEFFICIENT OF DISCHARGE WITH REYNOLDS NUMBER

of Fig. 2 shows that the length-diameter ratio is relatively unimportant, provided the same geometrical shaped nozzle is used. In the tests made with this 0.014-in. diameter orifice the length-diameter ratio was varied in successive steps of 3, 2, and 1. The results show that except at the lower injection pressures where there was a slight decrease, the coefficient remained constant at 0.94, the same value that was obtained with the orifice illustrated in Fig. 1.

If it is true that the orifice length-diameter ratio and orifice size have no effect on the coefficient of discharge providing the same geometrical shape of orifice is used, then the values of the coefficient of discharge plotted against the Reynolds number should give constant values. Fig. 3 shows the curve obtained when the data are plotted in this manner. It may be noted that the value of the Reynolds number investigated varies from 2000 to 12,000. The curve shows results obtained with orifices having diameters of 0.008 in., 0.014 in., and 0.020 in. for orifice length-diameter ratios of 1, 2, 3, and 4. The large values of the Reynolds number obtained even with the low injection pressures indicate that the flow in the orifice for all test conditions is within the range of turbulent flow.

In using the coefficient-of-discharge apparatus the nozzles to be tested are assembled in a special holder. Sufficient tests were made, however, with the nozzles mounted in an automatic injection valve having a low valve-opening pressure, to show that the spring-loaded stem above the orifice had no effect on the value of the coefficient.

Although the angle of 60 deg. was chosen arbitrarily because nozzles made at the laboratory have used this angle, the work by Zucrow (reference 3) has shown that this angle gives the maximum value of the coefficient.

The values of the coefficient of discharge have been used in determining the variation in oil pressure during the injection period of an injection system consisting of an injection pump having a constant-velocity cam and an automatic spring-loaded injection valve. The valve opening pressure was taken as 500 lb. per sq. in., and the orifice diameter as 0.020 in. The calculations were made for a pump speed of 750 r.p.m.

If no leakage past the pump plunger is assumed, the displacement of the plunger does two things; it compresses the fuel in

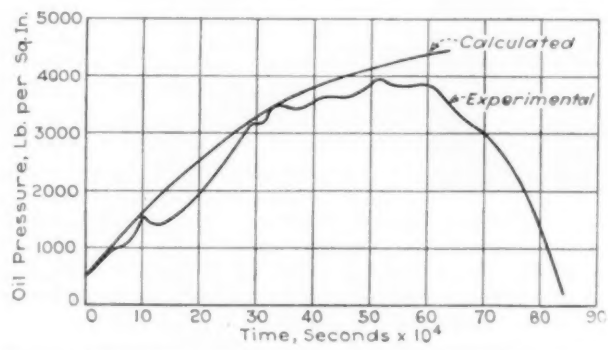


FIG. 4 COMPARISON OF CALCULATED AND EXPERIMENTALLY DETERMINED PRESSURES IN AN INJECTION PUMP

(Orifice diameter, 0.02 in.; valve-opening pressure, 500 lb. per sq. in.; pump r.p.m., 750.)

the injection system, and discharges fuel through the injection valve. By equating the rate of displacement of the pump to the rate of discharge through the orifice plus the rate of compression in the injection system, the instantaneous pressure at the discharge orifice can be computed. The decrease in volume of the fuel with pressure may be calculated from the information contained in reference 4. Knowing the diameter and coefficient of discharge of the orifice, the flow through the injection valve can be calculated by the familiar hydraulic formulas,

$$Q = A\ V\ t, \text{ where } V = C\ \sqrt{2g\ P/\rho}$$

The calculated injection pressures have been plotted in Fig. 4, for comparison with the experimental values of oil pressure determined from the stem-motion diagram of an automatic injection valve (reference 5). The agreement of the curves during the injection stroke of the pump plunger is good. The calculations have not been extended above 0.006 sec., since at about this time the bypass on the fuel pump opens. The curves indicate that for the period of injection during which the bypass valve is closed the instantaneous pressures may be calculated with a fair degree of accuracy.

INVESTIGATION OF SPRAY PENETRATION

At the same time that the work is being continued on the coefficient-of-discharge apparatus, the effect of injection pressure and chamber pressure on the spray penetration and spray shape

is being determined with the spray-photography equipment for the same orifices. The effect of injection pressure, chamber pressure, and orifice length-diameter ratio on fuel-spray penetration after 0.001 sec. is shown in the curves of Fig. 5.

The data were obtained for a 0.014-in. diameter orifice having length-diameter ratios of 2, 3, and 4. The valve-opening pressure was 2000 lb. per sq. in. The range of injection pressures investigated was from 2000 to 8000 lb. per sq. in., and the chamber pressures were varied from 65 to 250 lb. per sq. in. An examination of the surfaces which represent the data obtained for each orifice length-diameter shows that for any given injection pressure and chamber pressure increasing the orifice length-diameter ratio increases the spray penetration. At the low chamber, pressures increasing the length diameter from 3 to 4 results in

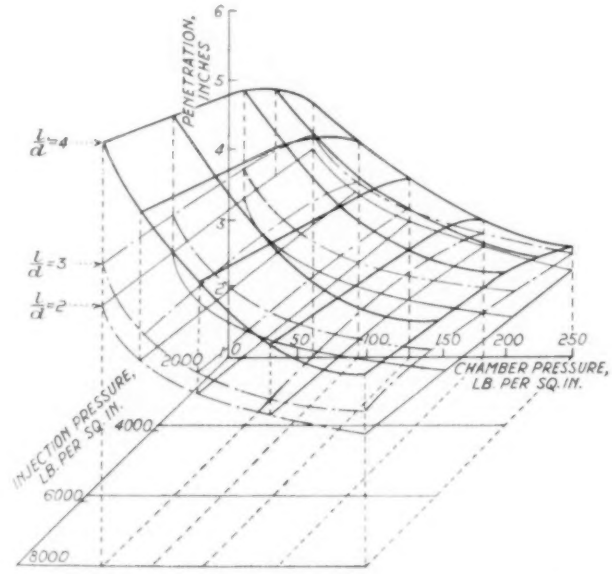


FIG. 5 EFFECT OF INJECTION PRESSURE, CHAMBER PRESSURE, AND ORIFICE LENGTH-DIAMETER RATIO ON SPRAY PENETRATION (Orifice diameter, 0.014 in.; valve-opening pressure, 2000 lb. per sq. in.; penetration, after 0.001 sec.)

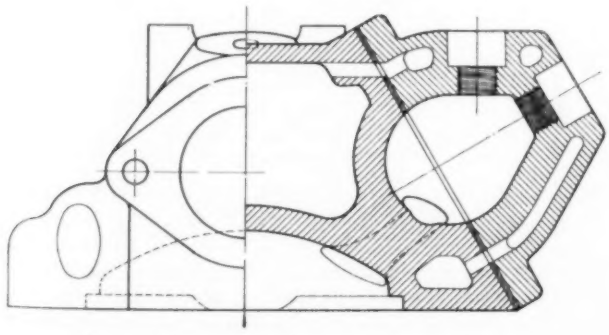


FIG. 6 COMBUSTION-CHAMBER DESIGN NO. 3

a greater increase in penetration than is obtained by increasing the length-diameter ratio from 2 to 3. As the chamber pressure is increased, however, this difference in penetration for equal increments of change in the length-diameter ratio decreases, until at a chamber pressure of 250 lb. per sq. in., the increase in penetration for a change in length-diameter ratio of 2 to 3 is about equal to that obtained by increasing this ratio from 3 to 4. Previous tests have shown that with centrifugal stems the maximum spray dispersion is obtained with orifice length-diameter ratios of 1.5 to 2 (reference 6). With the higher length-diameter ratio the spray angle is less, and the jet maintains a compact stream for a greater distance into the chamber before breaking down. This work will include similar information for a range of orifice sizes from 0.005 in. to 0.040 in., and for injection times of 0.001 sec., 0.002 sec., and 0.003 sec. Both plain- and centrifugal-injection valve stems will be used.

INVESTIGATION OF VALVE-STEM MOTION

Although it has been impossible to obtain a commercial indicator capable of indicating the instantaneous pressures obtained in the fuel-injection line during injection, a method has been developed which permits the determination of these instantaneous pressures from the photographic records obtained of the motion of the injection valve stem. By an analysis of these records, it has been possible accurately to determine the injection characteristics of a common-rail fuel-injection system.

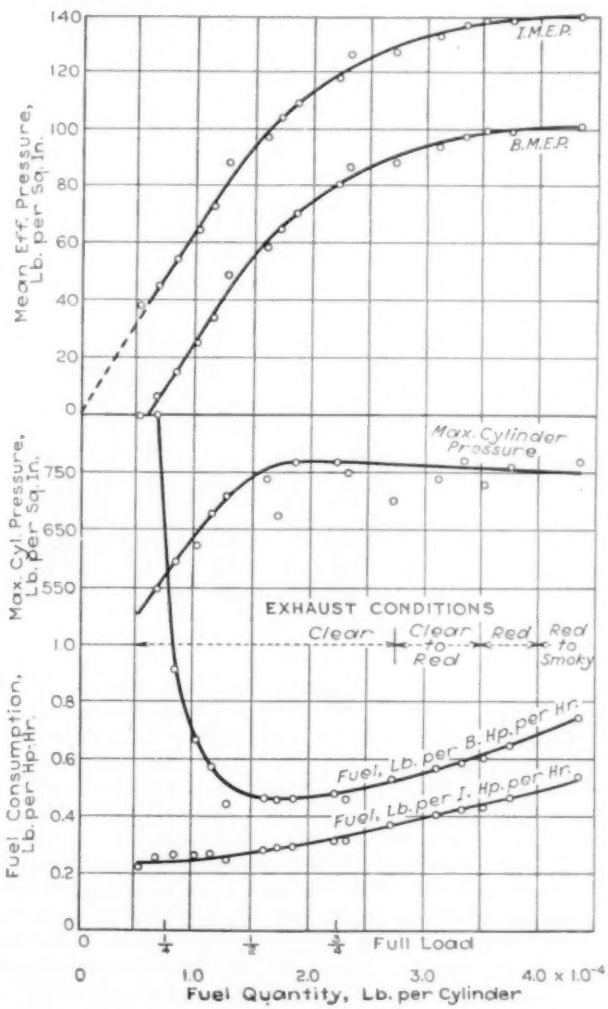


FIG. 7 EFFECT OF LOAD ON ENGINE PERFORMANCE WITH COMBUSTION-CHAMBER DESIGN NO. 3
(Bore, 5 in.; stroke, 7 in.; engine speed, 1500 r.p.m.)

COMBUSTION CHAMBER INVESTIGATION

There are two general methods for obtaining an intimate mixture of fuel and air in the cylinder of an aircraft Diesel engine. The fuel may be distributed throughout the air in the combustion

chamber by so proportioning and directing the fuel-injection orifices as to obtain the desired mixing, or a high velocity of air flow in the combustion chamber may be used to distribute the fuel. At present, research work is being conducted upon a combustion chamber representative of each of these methods of fuel-spray distribution.

The laboratory has stressed low maximum cylinder pressures for this type engine. The figure of 800 lb. per sq. in. has been arbitrarily taken as the maximum permissible cylinder pressure. It is advantageous to operate at low maximum cylinder pressures, because of the great increase in structural and maintenance difficulties which arise when higher pressures are used. It has been noted that all attempts to operate these test engines on a constant-volume cycle have usually resulted in decreased power.

A complete description of the cylinder head designed to investigate the effect of high air turbulence on fuel-spray distribution has been previously given in reference 7. A sketch of the cylinder head is shown in Fig. 6. This cylinder head consists of a pear-shaped bulb directly connected with the main cylinder through a $^9/_{16}$-in. diameter orifice set at an angle so as to give a high velocity of air flow within the bulb on the compression stroke of the piston and within the cylinder on the expansion stroke.

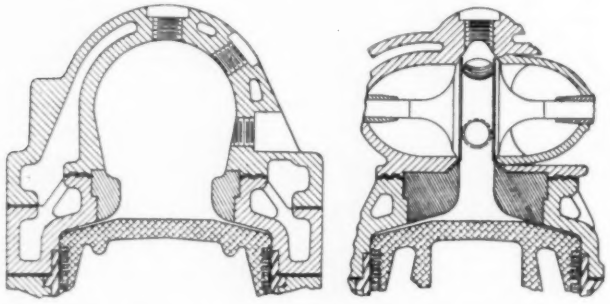


FIG. 8 COMBUSTION-CHAMBER DESIGN NO. 4

The fuel-injection valve is located along the center line of the bulb. With the present arrangement, the percentage of air within the bulb at the end of the compression stroke is 50 per cent. The increased engine performance over that previously reported has been obtained by using a cam-operated fuel-injection pump, a fuel-injection valve having a single 0.050-in. diameter orifice, and by using low valve-opening pressures.

Fig. 7 shows the engine performance obtained at a speed of 1500 r.p.m. with the cylinder head mounted on a 5-in. bore by 7-in. stroke test engine. The performance is plotted against fuel quantity in pounds per cycle. Full-load fuel quantity has been taken as the weight of fuel per cycle giving 15 per cent excess air. The outstanding point is the high indicated mean effective pressure obtained of 140 lb. per sq. in. with a maximum cylinder pressure of approximately 750 lb. per sq. in. The indicated power has been obtained by adding to the brake power the power required to motor over the engine with the dynamometer maintaining the same speed, water, oil, and air temperature as in the power run. The maximum cylinder pressures recorded have been indicated and checked by "trapped" pressure readings of a balanced-pressure disk-type indicator. The balanced condition of the disk is indicated by the flash of a neon lamp. The full-load performance of the engine gives an indicated mean effective pressure of 133 lb. per sq. in., and a fuel consumption of 0.40 lb. per i.hp. per hr. The corresponding brake mean effective pressure is 94 lb. per sq. in., and the fuel consumption 0.55 lb. per b.hp. per hr. The low mechanical efficiency of the engine at full load of 70 per cent is due in part to the high friction power necessary to force the air charge through the small-diameter orifice and the number of auxiliaries driven by the engine. The condition of the engine exhaust within 4 in. of the exhaust valve is also indicated on the performance curves. It may be noted that a clear exhaust is maintained from idling to 91 per cent of the full-load fuel. The maximum brake mean effective pressure obtained with a colorless exhaust is 91 lb. per sq. in., and the corresponding fuel consumption 0.52 lb. per b.hp. per hr. With increase in load the exhaust changes to dull red and finally becomes smoky. The maximum cylinder pressure increases with increase in fuel quantity until the maximum power with a colorless exhaust is reached. As the fuel is increased above the

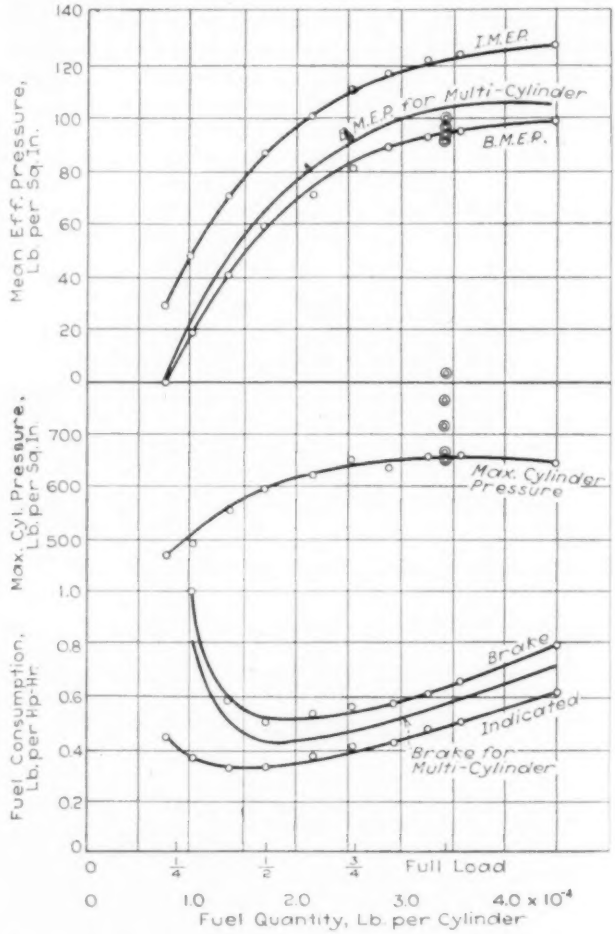


FIG. 9 EFFECT OF LOAD ON ENGINE PERFORMANCE WITH COMBUSTION-CHAMBER DESIGN NO. 4
(Bore, 5 in.; stroke, 7 in.; engine speed, 1500 r.p.m.)

full-load value, the maximum cylinder pressure remains practically constant, although the power continues to increase.

Although this type of combustion chamber is usually associated with relatively slow engine speeds, recent tests have shown that it is possible at 1500 r.p.m. to obtain a rate-of-pressure rise in the bulb of 1,080,000 lb. per sq. in. per sec. This rate-of-pressure rise is more than three times greater than that giving optimum performance in high-speed carburetor engines (reference 8).

COMBUSTION CHAMBER DESIGN NO. 4

The effect of fuel-spray distribution on engine performance has been determined for the combustion chamber design No. 4 shown in Fig. 8. This design is a vertical disk-type combustion chamber formed between horizontally arranged inlet and exhaust valves.

The cylinder head has been made with removable orifices between the upper part of the combustion chamber and the cylinder proper. The fuel-injection valve is mounted in the top of the combustion chamber. The engine performance shown in Figs. 9 and 10 was obtained with a cam-operated fuel-injection pump and an automatic spring-loaded fuel-injection valve. A uniform distribution of fuel throughout the air in the combustion chamber was obtained by varying the size, number, and direction of the orifices in the valve nozzle.

Fig. 9 shows the variation in engine performance with load for this cylinder head mounted on a single-cylinder test engine having

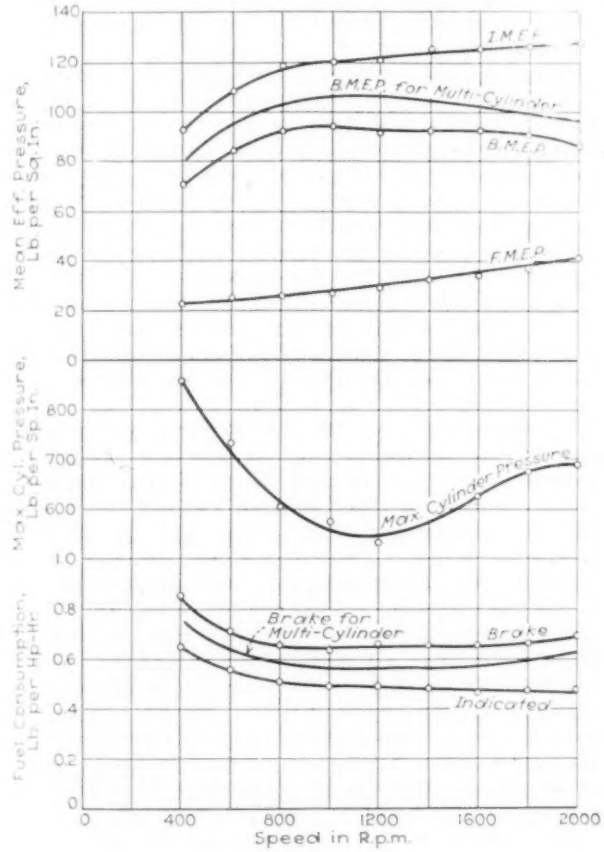


Fig. 10 Effect of Engine Speed on Performance at Full Load With Combustion-Chamber Design No. 4
(Bore, 5 in.; stroke, 7 in.)

5-in. bore by 7-in. stroke, and operated at a speed of 1500 r.p.m. The outstanding characteristic of this combustion chamber is the high brake mean effective pressure obtained with low maximum cylinder pressures. Since this engine has a higher volumetric efficiency than the No. 3 cylinder head, the full-load fuel quantity per cycle is increased. The full-load fuel quantity of 3.45×10^{-4} lb. per cycle in this case gives no excess air in the cylinder. The full-load mechanical efficiency of this test engine is 77 per cent, which may be compared with the value of 70 per cent recorded for the bulb-type cylinder head. Using the same values of indicated power and fuel consumption, the brake performance has been calculated for an assumed mechanical efficiency of 85 per cent. This value of mechanical efficiency is readily obtainable in multi-cylinder engines. The full-load brake mean effective pressure is then increased from 94 to 104 lb. per sq. in., and the corresponding fuel consumption decreased from 0.63 to 0.56 lb. per b.hp. per hr.

The effect on the full-load engine power of increasing the injection-advance angle so as to operate with higher maximum cylinder pressures is shown by the concentric circles. It may be noted that increasing the maximum cylinder pressure from 650

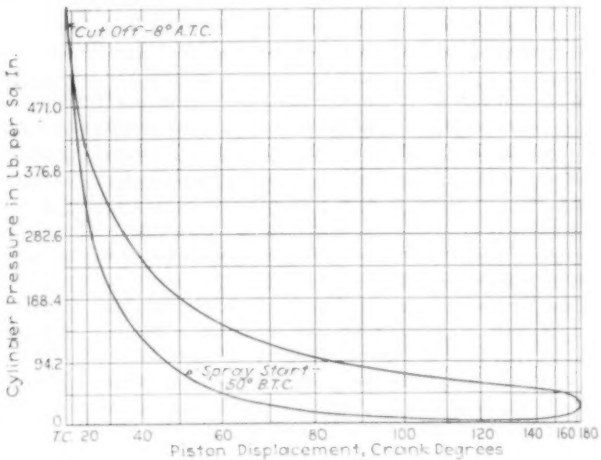


Fig. 11 Indicator Card Using Low Rate of Injection
(Bore, 5 in.; stroke, 7 in.; compression ratio, 13.5; engine speed, 1500 r.p.m.; brake horsepower, 19.5.)

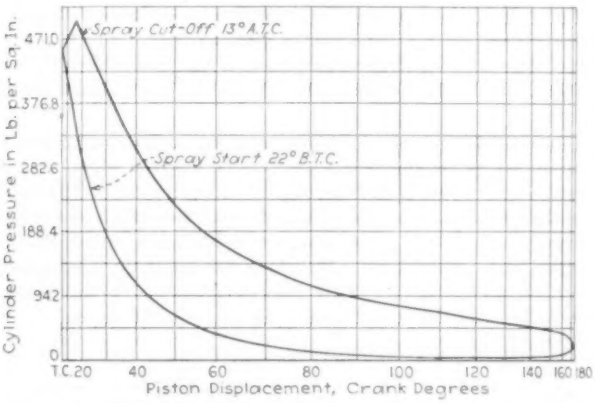


Fig. 12 Indicator Card Using High Rate of Injection
(Bore, 5 in.; stroke, 7 in.; compression ratio, 13.5; engine speed, 1500 r.p.m.; brake horsepower, 22.8.)

to 815 lb. per sq. in. increased the b.m.e.p. from 95 to 101 lb. per sq. in. The increase in injection advance angle necessary to obtain this increase in maximum cylinder pressure was only 8 deg. greater than the advance angle giving normal operation.

The effect of variation in engine speed from 400 to 2000 r.p.m. on the performance of the engine with the No. 4 cylinder head is shown in Fig. 10. The curve of maximum cylinder pressures shows a pressure of 850 lb. per sq. in. at an engine speed of 400 r.p.m. With increase in engine speed, however, the maximum cylinder pressure falls rapidly until a speed of 1200 r.p.m. is reached. Above 1200 r.p.m. the curve rises and reaches a value of approximately 700 lb. per sq. in. at a speed of 2000 r.p.m. The maintenance of a flat fuel consumption curve for a range of engine speeds from 800 to 1800 r.p.m. is of particular interest. The operation of the engine for the complete range of speeds is smooth and regular. No difficulty has been experienced in coking of the multi-orifice injection nozzles even when the engine is idled for several hours at a speed of 200 r.p.m.

Engine Indicators

Work is in progress on the design of a satisfactory optical-

type indicator for the aircraft-type Diesel engine. While this indicator is being developed, the work on the test engines has been greatly assisted by indicator cards obtained with a modified Farnboro indicator. The alterations made to the commercial indicator, which have improved its performance, have been an 80 per cent reduction in the weight of the operating disk, the reduction in the movement of the disk from 0.015 in. to 0.005 in., the elimination of the sliding contact between the disk and the central spindle, and the use of a new paper which permits a reduction in the primary voltage. The maximum cylinder pressures for the same engine-operating conditions have been determined from the indicator card and checked by the maximum-pressure indicator. The indicated power checks within 4 per cent the sum of the brake and friction power determined by motoring. The disadvantage of this type indicator is that it does not give the variation in pressure for each cycle.

Figs. 11 and 12 show indicator cards plotted from pressure-time records obtained with this indicator. The two different rates of combustion were obtained in the same engine under the same operating conditions by changing the rate of fuel injection. Fig. 11 shows a full-load indicator card obtained at an engine speed of 1500 r.p.m. when operating with the No. 4 cylinder head and a low rate of fuel injection. The time of spray start and cut-off has been determined with the oscilloscope and is indicated on the cards. This low rate of fuel injection gave a fast rate of pressure rise in the engine and a maximum cylinder pressure of 620 lb. per sq. in. The indicator card shown in Fig. 12 was obtained using a high rate of fuel injection. For this rate of fuel injection, the type of combustion and maximum cylinder pressure obtained is comparable to that of slow-speed Diesel engine.

The laboratory work of this research has yielded considerable information as to the characteristics of various types of fuel sprays when injected into air at low temperature. The next investigation will be the determination of the effect of various kinds and amounts of air flow on the combustion characteristics of these same fuel sprays. With this fundamental information available, the design of aircraft Diesel engines can be undertaken with far greater chances of producing a successful engine.

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Discussion

P. H. Schweitzer.[2] The investigations carried out by the N.A.C.A. constitute the most important source of knowledge on high-speed compression-ignition engines. Each of the three divisions of research fills a useful purpose. A fourth division, however, would have the object of testing Diesel engines in airplanes. No organization is more qualified than the N.A.C.A. to undertake such investigation and a lot of good should come out of it.

It is surprising that the value of the coefficient of discharge is so high for small orifices and that it is so constant over a wide range of pressures and length-diameter ratios. It shows the importance of the entering edge. Wherever it is true that the length-diameter ratio has no effect on the coefficient of discharge, it must be equally true that the viscosity has no effect on same. It would be interesting to check that with the respective orifices by heating the oil.

The writer would like to know the viscosity of the oil used in the tests. The high Reynolds numbers given would indicate that the oil used was extremely thin (one-tenth as viscous as water). For the Gulf black oil, which is one of the oils used, with a Saybolt viscosity of 1000 sec. at 80 deg. fahr., when flowing under 4000 lb. pressure through a 0.015-in. diameter orifice, the Reynolds number is 210. In this case there is a decidedly laminar flow and the Bernoulli formula should not be used without a viscosity correction which is 15 per cent at an l/d ratio of 2, 25 per cent at an l/d ratio of 5, and 37 per cent at an l/d ratio of 10. The writer recommends the use of a viscosity correction whenever the Reynolds number divided by the length per diameter ratio is below 100. This is likely to occur when the orifices are longer than four diameters.

Referring to Fig. 4, the writer would like to ask the author how the injection pressures have been calculated. To calculate the instantaneous injection pressures from the discharges by the hydraulic formula, the rate of discharge has to be known. Was this experimentally determined for the various phases of the injection?

The data given for the spray penetration are true apparently for very thin liquids only. Using ordinary Diesel oil of, say, 100 Saybolt viscosity, the increase of the length from 3 to 4 diameters will hardly result in a greater increase in penetration than is obtained by increasing the length-diameter ratio from 2 to 3; it is probable that the penetration will not increase at all when the length is increased beyond three times the diameter. The viscosity has a decided effect on all these characteristics, and the viscosity of one Diesel fuel oil is sometimes 100 times greater than the viscosity of another Diesel fuel oil.

The committee is to be complimented on the high mean effective pressures obtained with the experimental engines, which are frequently coupled with moderate explosion pressures.

The author mentions that all attempts to operate these test engines on a constant-volume cycle have usually resulted in decreased power. To what engines does the author refer? Does this mean that an advance in injection timing generally resulted in lower m.i.p.? That is contrary to common experience.

The writer has confidence in the no-turbulent type of combustion chambers for aviation purposes and is pleased to see the investigation which is promised in this direction.

Leigh M. Griffith.[3] In actual engine operation engineers are concerned with getting the fuel into the combustion chamber at the correct rate and with the proper degree of atomization and penetration. With a given fuel pressure, the desired rate of injection can be secured from a large orifice of low discharge coefficient, or from a small orifice of high coefficient, but one has little idea of the relative atomization and penetration. This would be a fruitful question to study. On the face of the matter,

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[3] Vice-President and General Manager, Emsco Aero Engine Co., Bell, Calif. Mem. A.S.M.E.

the large orifice of low coefficient would be preferable. It is less likely to clog, and is easier to drill accurately, inspect, and clean. Moreover, the rounding or countersinking operation at the entrance of the high-coefficient orifice may seriously complicate the nozzle design.

The engine test results reported for the two forms of cylinder head are somewhat discouraging, when compared to other recently reported results. At the speed of 1500 r.p.m. (1750 ft. per min.), the bulb-head gave 0.40 lb. per i.hp. per hr. at 133 lb. i.m.e.p., the maximum pressure apparently being about 750 lb. The No. 4 head gave an even poorer result of 0.455 lb. per i.hp. per hr. at 131 lb. i.m.e.p. and a maximum pressure of 815 lb. Such high indicated fuel consumptions show that the injection or combustion conditions were far from correct.

Some eight years ago, the British 8-in. by 11-in. laboratory Diesel engine gave about 0.36 lb. per i.hp. per hr. at 130 lb. i.m.e.p. and 1200 r.p.m. (2200 ft. per min.), with maximum pressure limited to 650 lb. When the maximum pressure was raised to 800 lb., the fuel rate dropped to 0.33 lb. and the i.m.e.p. rose to 136 lb. In fact, the N.A.C.A. research laboratory itself about the same time reported 0.36 lb. at 116 lb. i.m.e.p. and 1750 r.p.m. (2040 ft. per min.), while in 1925 it obtained a fuel rate of 0.33 lb. at 132 lb. i.m.e.p. at 1500 r.p.m. (1750 ft. per min.), the maximum pressures being described as "excessive" but not evaluated in either case.

It is interesting to compare the above figures with those recorded by H. R. Ricardo in *Automobile Engineer* for April, 1930. Working with a 5.5-in. by 7-in. engine, he obtained a fuel rate of 0.285 lb. per i.hp. per hr. at 122 lb. i.m.e.p. and 2200 r.p.m. (2570 ft. per min.), with a maximum pressure of 850 lb. Taking a mechanical efficiency of 85 per cent, this corresponds to 0.334 lb. per b.hp. per hr. and 104 lb. b.m.e.p. The Junkers two-stroke opposed-piston aircraft Diesel is reported to give under 0.38 lb. per b.hp. per hr. at 91 lb. b.m.e.p. and 1500 r.p.m. (2070 ft. per min.), but neither the maximum pressure nor the mechanical efficiency was stated. Assuming a mechanical efficiency of 80 per cent, which is reasonable for such a complicated mechanism, the indicated fuel consumption becomes 0.30 lb. and the i.m.e.p. is 114 lb.

It is pleasing to note that the development of a single-cycle indicator for high-speed Diesel-engine work is in hand. Although the writer's experience with the Farnboro indicator in high-speed Diesel development has been most satisfactory, he fully appreciates that a good single-cycle indicator would be of undoubted value for research work.

All of the essential requirements peculiar to the aeronautic Diesel engine have already been met separately, most of them several years ago, so that the development of other and larger aircraft Diesels awaits only the required engineering effort adequately financed.

Author's Closure

Referring to Dr. Schweitzer's discussion, the viscosity of the oil used in these tests is about 0.048 poises at 80 deg. fahr. and at atmospheric pressure. This corresponds to 45 Saybolt seconds. Data on the variation of the viscosity of this oil with temperature and pressure are given in N.A.C.A. Technical Note No. 315. Dr. Schweitzer's conclusion regarding the thinness of this oil was no doubt drawn from the curve of coefficients versus Reynolds' number given in the advance copy of this paper, which unfortunately was incorrect. The correct values are given in the final paper. The author agrees with the writer in the corrections applied to the Bernoulli formula; not only for the friction loss, if any, but also a correction to the basic formula. Bernoulli's equation assumes the kinetic energy of flow to be $V^2/2g$, whereas this can be true only when the velocity is uniform over the cross-section. For water and the normal distribution of velocity with turbulent flow the kinetic energy is known to be approximately 1.05 $V^2/2g$, and that for a laminar flow about $V^2/2g$, which is twice that given by Bernoulli's equation.

Results recently obtained at this laboratory confirm the writer's opinion that as the length-diameter ratio is increased a length may be reached at which a maximum penetration may be obtained. Increasing the length of the orifice beyond this point would probably result in either no further increase or, what is more likely, a decrease in the penetration. The length at which the maximum penetration is obtained during the first few thousandths of a second after the start of injection varies with the injection and chamber pressure and with the diameter

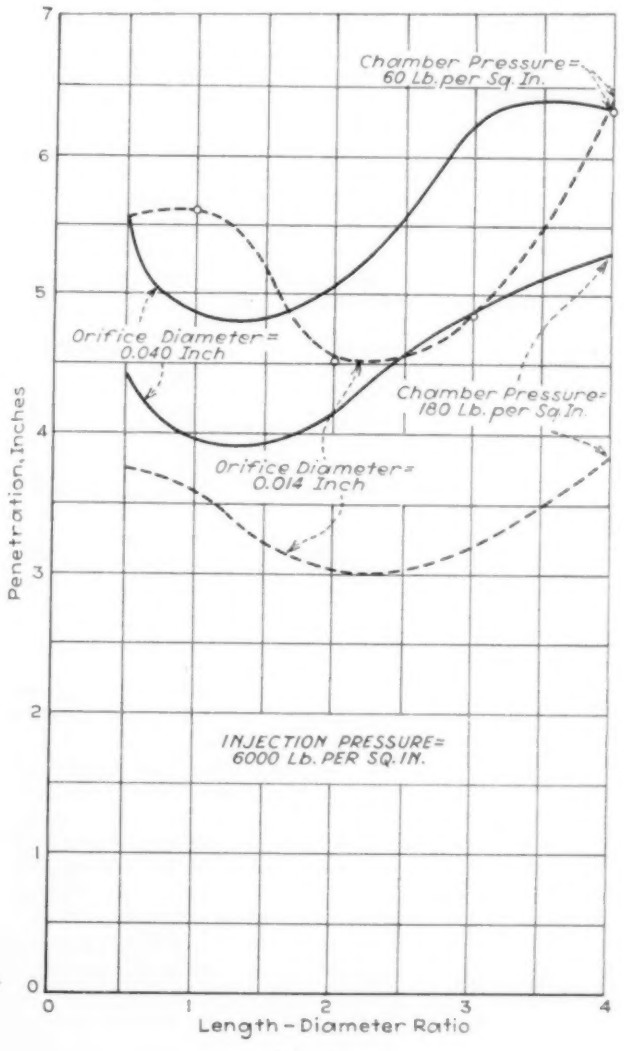


Fig. 13

of the orifice. Fig. 13 shows a set of curves obtained with two sizes of orifices for an injection pressure of 6000 lb. per sq. in. and chamber pressures of 60 and 180 lb. per sq. in. From these curves it will be seen that a maximum was reached at about a $1/d$ ratio of 4 for the 0.040-in. orifice. With the 0.014-in. orifice, however, the penetration appears to increase at a higher rate of the ratio between 3 and 4 with the smaller orifice, especially for the lower back-air pressure. The committee has

included in its program further tests with an 0.008 and 0.020 in. diameter orifice for $1/d$ ratios up to 10 which it is hoped will give the form of curves of penetration versus $1/d$ ratio after a maximum is reached. The author agrees with the writer that the viscosity has a decided effect on spray characteristics, and not only this, but also with the operation of the pump and injection valve when oil with a high viscosity is used.

Figs. 11 and 12 show the performance obtained when operating on the constant-volume cycle and the dual-combustion cycle. Advancing the time of injection does not necessarily change the combustion cycle of the engine. The effect on full-load performance of increasing the injection-advance angle is shown in Fig. 9. With this type of combustion chamber the increase in power is not proportional to the increase in maximum cylinder pressure, since a point can be reached beyond which the intensity of the engine knock increases with no further increase in engine power.

The injection pressures given in Fig. 4 were calculated from the known curve of plunger movement and the coefficients of discharge as experimentally determined. The assumption was made that there was no leakage past the pump plunger.

As to Mr. Griffith's discussion, a review of the report by H. B. Taylor entitled, "High-Speed Compression-Ignition Engine Research," which appeared in the July, 1928, issue of *The Journal of the Royal Aeronautical Society*, gives the following performance figures for the 8-in. bore by 11-in. stroke single-cylinder test engine designated as T-20:

Engine	Excess air	Speed	Maximum cylinder pressure	I.m.e.p.	I.f.c.	B.m.e.p.	B.f.c.	Mechanical efficiency
T-20	0.29	1200	650	121.4	0.396	107	0.45	0.881
Cylinder head No. 4	0.30	1200	650	117.8	0.386	88	0.51	0.748
Cylinder head No. 4	0.30	1500	650	112.5	0.390	85	0.55	0.750

These performance values may be compared with that of cylinder head No. 4 at a speed of 1500 r.p.m. and a fuel quantity of 2.65×10^{-4}, which gives an excess air coefficient of 1.30, as obtained from Fig. 9. The performance with this same cylinder head at 1200 r.p.m. and for the same excess-air coefficient has also been tabulated. The indicated mean effective pressure and fuel consumption obtained with the No. 4 cylinder head certainly compare favorably with those reported for the T-20. No mention is made in this report of the performance of 130 lb. per sq. in. indicated mean effective pressure and a fuel consumption of 0.36 lb. per indicated horsepower per hour under the conditions of engine speed and maximum cylinder pressure given by Mr. Griffith. The performance reported by H. R. Ricardo for a sleeve-valve engine using his "swirl type" combustion chamber is admittedly superior to any that has been obtained with a poppet-valve engine. In spite of the high performance quoted in laboratory tests, however, it is necessary to rate the Ricardo-Brotherhood engine at a brake mean effective pressure of only 83 lb. per sq. in. and a low speed of revolution. The low engine speed is necessary because of the high inertia forces of the sleeve and operating mechanism.

OGP-52-6

Diesel Power-Plant Records

By M. J. REED,[1] NEW YORK, N. Y.

The advice to keep records of Diesel-engine power-plant operation has been given often, but the author here states the kinds of records that should be kept and the inferences and conclusions that may be drawn from them. No attempt is made to draw up a general or standard power-plant log, but informative data are listed so that individual operators may decide how far they may wish to go in the recording of the performances of their plants.

THE advice to keep more and better records has been given often to Diesel power-plant operators. Not so frequently, however, have the preceptors stated what kind of records should be kept and what inferences can be drawn from these. In trying to detail this general advice no attempt will be made in this paper to draw up a standard power-plant log which could apply to any plant, under any conditions, anywhere. It is enough to try to point out what data are informative and what are not, and what deductions can be drawn from the former. With data so classified, individual operators can decide how far they wish to go in the recording of the performances of their plants.

Some data indicate how the Diesel plant is being operated at the moment only, but give no index of a permanent trend of affairs. Of such are circulating-water temperatures, injection-air pressures, etc. These could be called "operational" data. Other data apply to the actual condition of engines and point to a time when replacements will be needed. These could be called "maintenance" data. A third kind of data fixes the basis for the determination of the cost of the unit produced; these are "cost" data. The plan of this paper is to take up the various systems—i.e., the circulating-water system, the inlet and exhaust system, the lubricating-oil system, the fuel-oil system, and the output system—in turn to determine what information really tells a story and into what class of data it falls.

Fig. 1 is a diagram of a typical double-circuit water-circulating system with soft water for engine cooling and raw water for soft-water cooling. In this diagram the temperatures which are informative are indicated by T, with an identifying subscript. The engine inlet-water temperature T_a is important in relation to the discharge temperatures T_b, T_c, T_d, T_e, T_f, T_g. The spread, or rise, should not exceed 30 deg. fahr. for any system and preferably not 15 deg. fahr. for a double circuit such as is illustrated. The discharge temperature T_b to T_g should not fall below 100 deg. fahr. or climb above 130 deg. fahr. for best results. Higher discharge temperatures may cause the cylinder lubrication to break down from overheating; lower discharge temperatures are not favorable to the best combustion. The one case calls for more soft-water circulation or more raw-water circulation, or both; the other calls for less circulation.

The diagram shows a bypass connection between the discharge of the soft-water pump and the soft-water reservoir. A bypass connection of this sort should be installed in all cases where very cold circulating water is available. Even for systems of the type illustrated, it is better to adjust for temperatures by means of such a bypass than by throttling the circulating pump.

Discharge temperatures from 100 to 130 deg. fahr. should be maintained throughout the load range. In fact, it is most important that these temperatures be not lowered at low loads, for it is at these loads that combustion would suffer most from low cylinder temperatures.

The temperatures T_b, T_c, and T_d should be approximately alike. The same specification holds for T_e, T_f, and T_g. Unequal temperatures indicate unequal water distribution, which should be corrected by throttling the lines to the cold cylinders (or pistons, as the case may be). Of course, the exhaust pyrometer should be first consulted to see if cylinder loadings are alike before concluding that water distribution is responsible.

The only benefit obtained by requiring these temperatures to be recorded hourly is a sort of insurance that the shift engineer is reading the thermometers and making the indicated adjustments. The readings cannot indicate anything about carbonization or scale, since the amount of water being circulated is unknown, nor would it be practical to meter it accurately. If an owner wishes to be sure his engineer is on the job, the shift report should call for hourly entries of these temperatures. It would be foolish, however, to clutter up a monthly report with this kind of information.

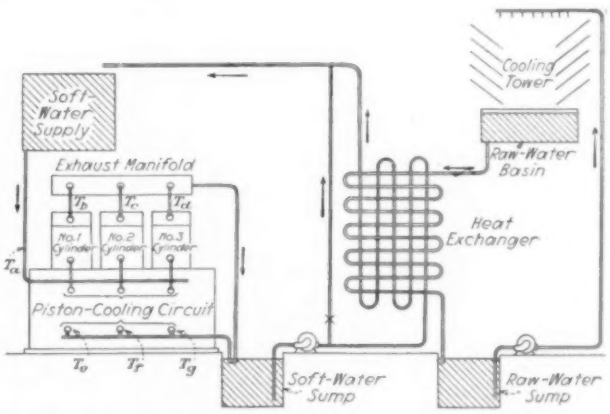


FIG. 1 TYPICAL DOUBLE-CIRCUIT WATER-CIRCULATING SYSTEM

Raw water conditions—i.e., the outside wet- and dry-bulb temperatures, and the temperatures in and out of the heat exchanger—are very important considerations when a plant is being designed, but become entirely secondary after it is put in operation. The raw-water system does not matter so long as the soft-water temperatures are satisfactory. Should trouble show up in the soft-water system, the raw-water system may be adjusted, but the soft-water thermometers tell whether the adjustment has been satisfactory. The temperature of the soft water as it leaves the exhaust manifold is not important unless it climbs high enough to effect T_a.

Circulating water should be supplied to an engine by gravity from an elevated tank. An alarm operated by a float in the tank is usually provided to give warning of low water level. Therefore the pressure of the circulating water at the engine is not of interest; it is either sufficient or the alarm is sounding.

Fig. 2 illustrates an inlet and exhaust system as applied to one cylinder. Air at atmospheric pressure and temperature P_a and T_a is led to the cylinder through the inlet piping. Here it is compressed to pressure P_b, supports combustion, and ex-

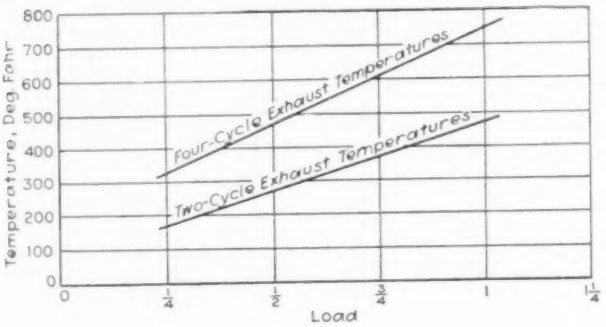
[1] Research Engineer, Diesel Engine Manufacturers' Association.

Presented at a meeting, November 26, 1929, of the Oil and Gas Power Section of the Philadelphia Section of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

hausts at temperature T_c. Variation of 1 in. in barometric pressure P_a will account for approximately 0.01 lb. variation in the fuel rate per brake horsepower hour, the higher barometer corresponding to the better fuel rate. A variation of 20 deg. in inlet temperature corresponds to a similar variation in the fuel rate, the lower temperature corresponding to the better fuel rate. Plant operators who insist upon this degree of fineness in their records should read and record intake pressure and temperature once per shift. Intake temperature should be read at or near the actual intake, however; not in the engine room for an outside intake, nor outside for an engine-room intake.

The compression pressure P_b is highly important. Poor compression means poor combustion; poor combustion brings about poorer compression; and so on in a vicious circle. Compression pressure should be read from a pull card once per month, or at least four times per annum. It is a good idea to plot these compression readings against time, or hours of operation. The resulting curve will indicate the progressive condition of the piston rings.

The exhaust temperature T_c is not so important in itself as in



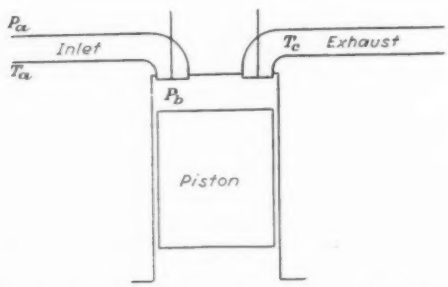


FIG. 2 INLET AND EXHAUST SYSTEM AS APPLIED TO ONE CYLINDER

relation to the exhaust temperatures of the other cylinders. An appreciable difference in exhaust temperatures means unequal cylinder loadings. If piston rings and valves are in proper shape, such inequalities can be reduced by regulating the amounts of fuel delivered by the injection pumps.

Too much reliance should not be placed on pyrometer readings unless the elements are inspected occasionally. A dirty element may cause a low reading. Increased fuel injection in that case would tend to foul the element all the more, thus depressing the reading still further.

Exhaust temperatures should be read every hour. Therefore if a record is considered desirable, entries should be made hourly. Once the record has been gone over to see that cylinder temperatures are roughly equal and that the average is not abnormal, the information has served its purpose and should not be transferred to monthly records. The curves in Fig. 2 show what exhaust temperatures are normal over the load range.

This completes the inlet and exhaust system for mechanical-injection engines. Air-injection engines, however, have injection-air pressures to be observed in addition. For best combustion the injection-air pressures at various loads should be approximately as shown in Fig. 3. This diagram also shows the normal variation of intercooler pressures. An intercooler pressure much above the amounts shown indicates valve trouble in the stage drawing from the intercooler, whereas a subnormal intercooler pressure points to the stage delivering to the intercooler. These pressures, including the injection pressure, should be observed every hour, and, if recorded, should be recorded once per hour.

A typical lubricating-oil system is illustrated in Fig. 4. The

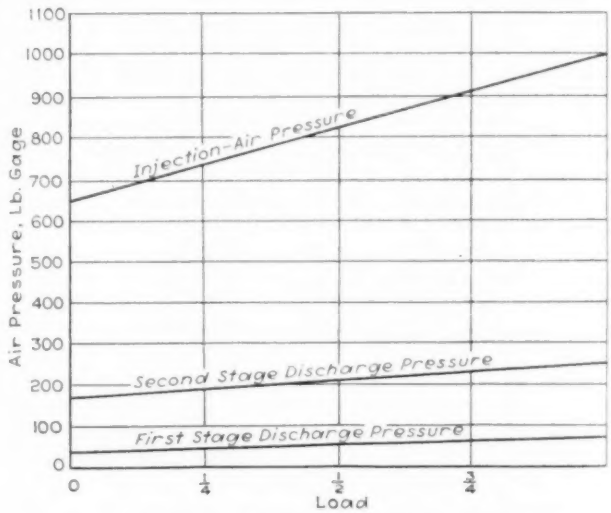


FIG. 3 RANGE OF INJECTION-COMPRESSOR PRESSURES

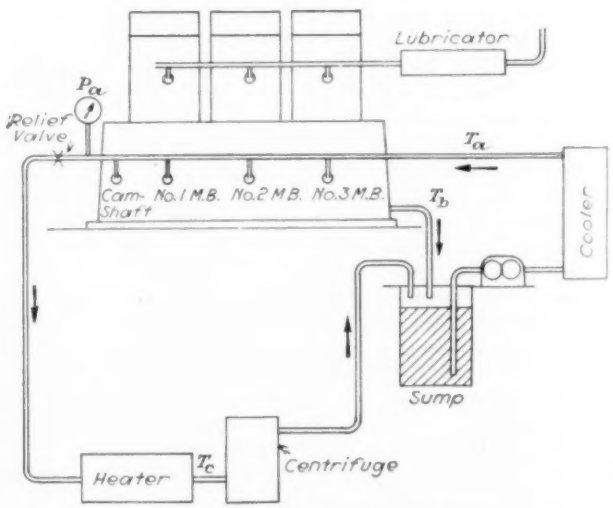


FIG. 4 TYPICAL LUBRICATING-OIL SYSTEM

engine cylinders are served with oil by drop feed. Force-feed lubricates the main bearings, connecting rods, and camshaft bearings. A part of the oil in circulation is bypassed continuously through a centrifuge. All of the oil in circulation passes through a cooler.

The only observable information of the drop-feed system is the number of drops per minute. The force-feed pressure P_a varies for different makes of engines. Whatever is normal for the engine is what should be held. A gradual fall in pressure in-

dicates bearing wear or pump wear. A sudden fall in pressure means a burnt-out bearing or a broken load. An increase in pressure may mean a clogged load.

If the crankcase temperature T_b does not exceed 135 deg. fahr. without cooling, no cooling is necessary. However, cooling the oil to a temperature of 90 to 100 deg. fahr. at the force-feed header will improve the lubricating-oil economy. The header temperature with a cooler should be not over 100 deg. and the crankcase temperature T_b should not be over 135 deg., with or without a cooler. Before the oil enters the centrifuge it should be heated to 160 deg. for effective purification. An increase in crankcase temperature may mean a hot bearing. The temperatures and pressure of the lubricating oil system should be read once each hour and, if recorded, should be set down as often.

The amount of new lubricating oil added to the system of each engine is data that should be logged in every plant without fail. Not only should the gallons added to each engine (not the amount added to all engines as a whole) be logged in the shift report and transferred to the monthly report, but an independent check should be made by recording the total amount of unused oil on hand on the first of the month being reported, the amount of oil bought during the month, and the amount of unused oil on hand the first of the month following. The monthly report should show the net amount of lubricating oil used per engine as calculated by the first method and the total net amount used for the plant as calculated by the second method.

When operated at a constant speed, an engine will use a constant amount of lubricating oil per hour no matter what the load may be. Therefore, the engineer should multiply the engine rating in horsepower by the number of hours operating and divide by the number of gallons used during the month to arrive at the number of rated horsepower hours per gallon for his monthly report. If the average speed of the engine was below the full rated speed, the rating should be scaled down in proportion for this calculation. This chart gives a good index of the efficiency of lubrication. One gallon of oil per 2000 rated horsepower-hours is fair; one gallon per 3000 rated horsepower-hours is good (in both cases without centrifuging).

Of course, the office should record the price paid for lubricating oil and should calculate and record the lubricating oil cost per unit generated. The office should also keep a record of the brands used and the economy reached with each brand. Manufacturers will recommend satisfactory brands of oil, but they cannot draw too fine a line between good oils and excellent oils. The user must do this by consulting his records.

The temperature of the fuel oil at the engine-injection pump is of importance only when using a heavy oil which must be heated. In that case, there will be a temperature below which the oil can be pumped but will not atomize satisfactorily. An hourly record of the fuel-oil temperature will tell whether the engineer is maintaining this minimum temperature. The oil company supplying the oil in question can advise what the minimum temperature should be.

The amount of fuel oil used is a figure of even more importance than the same information for lubricating oil. It should be reported by each shift engineer for each engine in gallons per shift. The determination should be based upon day tank readings—meters are not accurate enough. The total for the plant per month should be independently checked in the same manner as outlined for lubricating oil. Both the total for each engine for the month as arrived at from the shift reports and the total for the plant as determined by the independent check should be entered on the monthly report.

It is well to have the shift engineers report the number of units generated per gallon in their shifts. The office can easily prepare a curve showing at a glance the number of units that would be generated at any load factor with normal fuel economy. Such a curve as worked out for a given test performance and a given generator efficiency and a given fuel is shown in Fig. 5. Should the actual performance be poorer than the curve indicates, the engineer knows he should look for trouble in the engine valves, rings, spray nozzles, etc.

The office should record the price paid for all fuel oil and should reduce the total cost to the cost per unit generated during the month. In addition, the office should make a record of the following fuel-oil properties for each shipment:

Gravity in degrees A.P.I.
B.t.u. per pound
Viscosity in seconds Saybolt Universal at 100 deg. fahr. or other standard
Conradson carbon, per cent by weight
Sulphur, per cent by weight
Ash, per cent by weight
Water and sediment, per cent by volume
Flash point

Any reliable company can supply this information for the oil it sells. Gravity and B.t.u. per pound are necessary in calculating the number of pounds per gallon and the relation of the oil bought to the oil used as a basis for engine guarantees. Viscosity is important for its bearing upon heating. Flash point must be a certain figure to meet local insurance requirements.

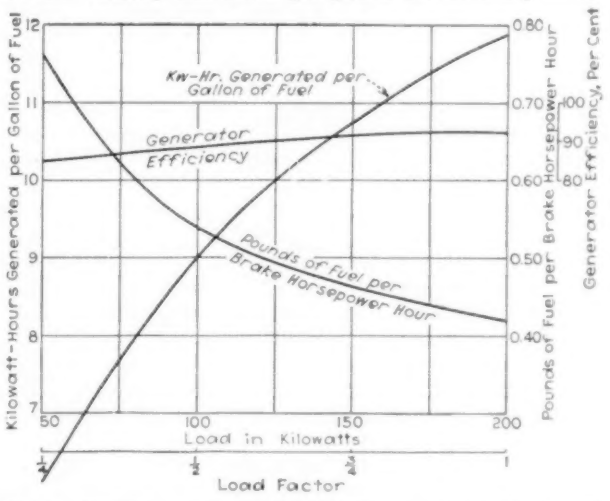


FIG. 5 NUMBER OF UNITS GENERATED AT ANY LOAD FACTOR

The carbon content has a pronounced influence upon combustion if appreciable. Both carbon and ash are believed to contribute to liner wear. The only method of determining how poor an oil (and, of course, how cheap an oil) can be profitably used is to watch the engine performance in respect to fuel consumption and liner wear and the balance against oil price. Engine manufacturers cannot help much to strike this balance; they cannot operate individual engines for long enough periods.

Before leaving the subjects of fuel oil and lubricating oil, emphasis might well be given to the necessity of laying out the plant in such a way that the consumption of fuel and lubricating oil can be ascertained per engine. The average of one good engine and one poor one is two fair engines. The good one misses well deserved credit; the poor one escapes a needed investigation.

Each shift should report the number of gallons of make-up water added to the soft- or raw-water systems and the number of pounds of treating compound used if water is treated. These amounts should be totaled in the monthly report and the cost should be recorded by the office. Any other supplies should be described in the shift report as used. The office should total the

TABLE 1 MAINTENANCE LOG FOR DE LA VERGNE VERTICAL DIESEL ENGINES

Station No.....
Engine No.....
Date, from.....to.....
Number of hours actual running for interval specified.....

No.	Items to be inspected	Recommended Max. hours of operation	Max. elapsed time (months)	Date work was done: Cyl. 1	Cyl. 2	Cyl. 3	Cyl. 4	Cyl. 5	Cyl. 6	Remarks
1	Pistons. Taken out and cleaned	6000	12							
2	Exhaust valves. Cleaned and ground	750	3							
3	Inlet valves. Cleaned and ground	1500	6							
4	Air starting check valves. Cleaned and ground	4000	6							
5	Air starting valves. Cleaned and ground	4000	6							
6	Fuel pumps. Valves cleaned and ground. Plunger examined	4000	9							
7	Spray checks. Test tightness each time engine is shut down	..	..							
8	Camshaft gears or chains. Check and adjust if necessary	4000	..							
9	Governor. Examined and adjusted	8000	..							
10	Wristpin bearing. Checked and adjusted each time pistion is removed	..	..							
11	Crankpin bearing. Checked and adjusted	3000	..							
12	Main bearings. Checked and adjusted. Alignment checked whenever crankpin bearings are adjusted	8000	..							
13	Lubricating tanks, lines and passages. Cleaned	8000	12							
14	Lubricating piping. Examined for leakage and loose joints	1500	2							
15	Lubricating oil filter. Cleaned. (Filter bags should be cleaned each shift)	2000	3							
16	Lubricating oil pump. Examined	4000	6							
17	Cylinder head jackets. Examined and cleaned	750	..							
18	Cylinder jackets. Examined and cleaned	4000	..							
19	Lubricating oil. Exchange batches	750	..							
20	Crank case. Flush out	4000	..							
21	Air tanks. Drain water and oil	200	..							

cost of all supplies used during the month and reduce the figures to the cost per unit generated. Each shift should report the men on duty and the number of hours worked by each. The office should total the attendance cost for the month and reduce the figures to cost per unit generated. Whenever extra labor is required to assist in making repairs, the cost of the extra labor should be considered a part of repair cost, not a part of regular attendance costs.

Repair parts should be listed in the shift report when used. The reason for the repair should be set down briefly. If an accident has occurred, the cause should be outlined. Repairs fall generally into three classes: (1) Repairs to correct wear (normal). (2) Repairs to rectify accidents (abnormal). (3) Repairs to modernize design (betterments).

Repair costs, to be fully illuminating, should also be broken down along these lines. In any case the office should keep accurate costs covering all repairs and extra labor required to make them.

Table 1 is a maintenance log prepared by a manufacturer of four-stroke cycle, mechanical-injection engines. The only criticism the author has to offer is that the form should call for the liner wear. This should be recorded in thousandths whenever observed for any type of engine. The figures should be reduced to wear per 1000 hours of operation per inch of piston diameter. One manufacturer stated that a wear of 0.0002 in. per inch is normal at the top of the piston travel for 1000 hours. Another manufacturer believes that normal wear is somewhat less than this.

Diesel engines vary so widely in type and design that it would be impossible to draw up a standard maintenance log. Fortunately, it is not necessary to attempt this. Manufacturers of engines are very glad to furnish users with detailed advice along this line and many have printed forms applying particularly to their engines.

Next is the measurement of the unit produced by the plant. In the case of generating units it is kilowatt-hours. Every generating plant should have integrating watt-hour meters, one for each engine and one for the net plant output. A similar allocation of recording indicating watt-meters is desirable, although not quite so essential as the watt-hour meters. The shift engineer should read the integrating meters each hour and report the kilowatt-hour production per engine per shift and the net plant output per shift. He should also report the fifteen-minute peak load for his shift for each engine and for the plant. This peak load should be read from the record of the indicating meters. The monthly report should show the total kilowatt-hours per unit per day, the total for the plant per day, and the totals in each case for the month.

The shift report should state the number of hours each unit was operated. From this the load factor for the unit should be calculated—the ratio of the kilowatt-hours generated to the number that would have been generated had the unit been operating at full load while running. This load factor is useful in connection with the number of units generated per gallon of fuel, as was explained previously. The monthly report can show the average load factor per month for comparison with the average number of kilowatt-hours generated per gallon of fuel.

There are a number of items of information which have no bearing on Diesel operation, as distinct from steam operation, but which are required for their bearing on the electrical operation. For instance, amperes per phase and voltage are needed to discover the power factor. Speed, constant enough not to affect lubricating-oil consumption in the case of generator units, is needed to determine cycles. The feeder-circuit-current distribution does not affect Diesel economy, but can be very important to the plant as a producer of electrical energy.

Diesel-operated pumping plants should record the integrating venturi-meter reading hourly. The monthly report should set down the gallonage by days and the total for the month. Hourly readings should be taken for both suction and discharge heads. These should be averaged for days and for the month in the monthly report. Many pumping plants are very particular about capacity, but make no effort to arrive at the average total pumping head. This is like measuring amperes, but not volts. Pumping costs should be reduced to the unit of 1,000,000 ft-lb. of water pumped.

The final unit in an ice plant is of course a ton of ice. However, there are so many conditions outside of the Diesel engines which can influence the cost per ton of ice that more data than the number of tons of ice are desirable. The average suction pressure and the average head pressure compiled from hourly readings, together with the average revolutions per minute, will fix the number of tons of refrigeration, assuming saturated gas in the suction line. A ton of refrigeration is a better unit than a ton of ice because it is more independent of other factors and, in addition, takes account of storage. The engineer of a Diesel-driven ice plant should also keep a record of condensing-water temperatures and ice-making-water temperatures to check up on his general plant operation as distinct from the purely Diesel end of operation.

The data discussed in this paper are presented herewith in itemized form, with the conclusions set down opposite.

Item	Engineer's reports: Daily	Monthly	Office record
Circulating-Water System:			
Temperature at engine inlet	Yes, hourly	No	No
Temperature at cylinder outlets	Yes, hourly	No	No
Temperature at piston outlets	Yes, hourly	No	No
Cost of make-up and treatment	(See supplies)		
Inlet and Exhaust System:			
Air temperature at engine inlet	(?), once per shift	(?), daily average	(?), monthly average
Barometer	(?), once per shift	(?), daily average	(?), monthly average
Compression pressure	No	Yes, once per month	Yes, once per month
Temperature, each cylinder exhaust	Yes, hourly	No	No
Injection air pressure:			
Final	Yes, hourly	No	No
Each cooler	Yes, hourly	No	No
Lubricating-Oil System:			
Force-feed pressure	Yes, hourly	No	No
Crankcase oil temperature	Yes, hourly	No	No
Temperature to centrifuge	Yes, hourly	No	No
Temperature from cooler	Yes, hourly	No	No
Gallons of new oil added for each engine	Yes, by shifts	Yes, per day	Yes, per month
Gallons on hand, 1st of month	No	Yes	Yes
Gallons bought during month	No	Yes	Yes
Gallons on hand 1st of following month	No	Yes	Yes
Total gallons used by plant during month	No	Yes	Yes
Cost of each shipment	No	No	Yes
Cost of oil used per month	No	No	Yes
Lubricating-oil cost per kw-hr. (or other unit)	No	No	Yes
Rated hp-hr. per gal. each unit	No	Yes	Yes
Fuel-Oil System:			
Temperature at injection pump	Yes	No	No
Gallons used per unit	Yes, per shift	Yes, per day	Yes, per month
Gallons on hand, 1st of month	No	Yes	Yes
Gallons bought during month	No	Yes	Yes
Gallons remaining 1st of following month	No	Yes	Yes
Total gallons used in month	No	Yes	Yes
Price paid, each shipment	No	No	Yes
Total cost of oil used in month	No	No	Yes
Fuel cost per kw-hr.	No	No	Yes
Gross kw-hr. per gal. each unit	Yes, by shifts	Yes, daily average	Yes, monthly average
Characteristics of fuel (see text)	No	No	Yes
Supplies:			
Gallons make-up water added	Yes, per shift	Yes, per day	Yes, per month
Pounds of treating compound used	Yes, per shift	Yes, per day	Yes, per month
Cost of make-up water	No	No	Yes, per month
Cost of treating compound	No	No	Yes, per month
Other supplies used, description	Yes, by shifts	No	No
Cost of other supplies	No	No	Yes, per month
Total cost of supplies	No	No	Yes, per month
Cost per kw-hr. of supplies	No	No	Yes, per month
Repairs:			
Description of parts	Yes, by shifts	Yes	Yes
Cost of parts	No	No	Yes
Cost of repairs to renew wear, parts	No	No	Yes, monthly
Extra labor	No	No	Yes, monthly
Cost of repairs to renew breakage, parts	No	No	Yes, monthly
Extra labor	No	No	Yes, monthly
Cost of repairs to modernize design, parts	No	No	Yes, monthly
Extra labor	No	No	Yes, monthly
Total cost of repairs, material, and extra labor	No	No	Yes, monthly
Repair cost per kw-hr.	No	No	Yes, monthly
Cause of any accidents	Yes	Yes	Yes
Attendance:			
Men on duty	Yes, by shifts	Yes, man-hours per day	Yes, man-hours per month
Hours for each man			
Extra labor for repairs	Yes, man-hours	Yes, man-hours	Yes, man-hours
Cost of extra labor	No	No	See under "Repairs"
Cost of attendance	No	No	Yes, monthly
Cost per kw-hr.	No	No	Yes, monthly
Load Data (Electrical):			
Kw-hr. generated per unit	Yes, readings each hour	Yes, per day	Yes, per month
Net kw-hr. station output	Yes, readings each hour	Yes, per day	Yes, per month
Peak load for 15 min.:			
Per unit	Yes, per shift	Yes, per day	Yes, per month
Per station	Yes, per shift	Yes, per day	Yes, per month
Amperes per phase, each unit	Yes, hourly	No	No
Volts	Yes, hourly	No	No
Power factor	Yes, hourly	Yes, daily average	Yes, monthly average
Feeder distribution, kw-hr. per circuit	Yes, per hour	Yes, per day	Yes, per month
Hours of operation, per unit	Yes, by shifts	Yes, per day	Yes, per month
Load factor, per unit	Yes, per shift	Yes, per day	Yes, per month
Auxiliary load (unit totals minus station net), kw-hr.	Yes, by shifts	Yes, per day	Yes, per month
Revolutions per minute (cycles)	Yes, per hour	Yes, daily average	Yes, monthly
Load Data (Pumping):			
Venturi meter	Yes, hourly	Yes, daily capacity	Yes, monthly capacity
Suction pressure	Yes, hourly	Yes, daily average	Yes, monthly average
Discharge pressure	Yes, hourly	Yes, daily average	Yes, monthly average
Total head	Yes, hourly	Yes, daily average	Yes, monthly average
Million foot-pounds	No	Yes, daily	Yes, monthly
Million foot-pounds per 100 lb. fuel	No	Yes, daily	Yes, monthly
Auxiliary power generated, kw-hr.	Yes, per shift	Yes, per day	Yes, per month
Hours operating, each unit	Yes, per shift	Yes, per day	Yes, per month
R.p.m., each unit	Yes, hourly	Yes, daily average	Yes, monthly average
Load Data (Refrigeration):			
Suction pressure	Yes, hourly	Yes, daily average	Yes, monthly average
Head pressure	Yes, hourly	Yes, daily average	Yes, monthly average
Condensing water temperature	Yes, hourly	Yes, daily average	Yes, monthly average
Ice-making water temperature	Yes, hourly	Yes, daily average	Yes, monthly average
R.p.m. each unit	Yes, hourly	Yes, daily average	Yes, monthly average
Hours operating, each unit	Yes, per shift	Yes, per day	Yes, per month
Tons refrigeration	No	No	Yes, per month
Tons ice made	Yes, per shift	Yes, per day	Yes, per month
Auxiliary load, kw-hr.	Yes, per shift	Yes, per day	Yes, per month
Maintenance Data:			
(See form for maintenance record attached)			
Also liner wear in thousandths	Enter as observed		Yes, total and per 1000 hr.
Recapitulation:			
Fuel cost per unit	No	No	Yes, monthly
Lubricating-oil cost per unit	No	No	Yes, monthly
Attendance cost per unit	No	No	Yes, monthly
Supply cost per unit	No	No	Yes, monthly
Repair cost per unit	No	No	Yes, monthly
Total cost per unit	No	No	Yes, monthly

Results of Some Tests by Industry of Sample Diesel Fuel Oil[1]

Progress Report No. 2 of the A.S.M.E. Special Research Committee on Diesel Fuel-Oil Specifications[2]

THIS committee delivered a Progress Report at the Annual Oil and Gas Power Convention at Penn State in June, 1929, in which its tentative specifications as recommended for Diesel engines were reported for the first time.

Oil engines in this country were divided into two classes and designated as "heavy duty" and "light high speed." The specifications advanced at that time for the two classes were as follows:

	Heavy duty	Light high speed
Viscosity at 100° F. (Saybolt Universal)	Max. 200 sec.	Min. 45 sec. Max. 100 sec.
Sulphur	Max. 3% by wt.	Max. 2%
Conradson	Max. 4%	Max. 1%
Ash	Max. 0.08%	Max. 0.02%
Flash	Min. 150 ° F.	Min. 150° F.
Moisture and sediment	Max. 1%	Max. 5%

NOTE: *Specific Gravity or A.P.I.* Gravity is of no importance as it pertains to the burning qualities of an oil. It should be given, however, by the supplier in order that weight per gallon can be computed.

The committee also qualified these specifications and explained the reasons for the adoption of each item and the relative merit of the various qualities. It is not within the jurisdiction of a research committee to set standards. Our function is to recommend to a standards organization what we consider acceptable Diesel specifications after a thorough investigation of types and classes of engines, conditions among the users of oil engines, and limitations and qualifications of oil refiners and distributors. After this information has been correlated, it is then necessary to proceed with the research and development work to a point where the committee can advise as to the practical application of such specifications in actual commercial Diesel-engine installations. To this end the committee sent out an appeal to the manufacturers of Diesel engines requesting that they run actual tests in engines of their design on oil meeting the maximum specifications as tentatively submitted for the two general types in order to supply it with complete information on the function of such oils. A form was drawn up for the reporting of test information in order that the data could be readily correlated and submitted to the committee for its information.

To date oil has been supplied to the Electric Boat Company, the Ingersoll-Rand Company, Fairbanks, Morse & Co., Nordbert Manufacturing Company, Cooper-Bessemer Corporation, I. P. Morris & De La Vergne, Inc., International Harvester, and also to the Zenith-Detroit Corporation for test in Diesel-engine fuel-oil filters. Captain Dinger, chairman of this committee, has at his disposal three Diesel engines on test blocks and several small units installed in motor boats. Oil was also submitted to him for operation of these units. We have received to date some detailed reports from companies testing this oil and have included some of the pertinent data in this report. It must be remembered that these tests are not conclusive nor is information contained herein sufficient proof to the committee that the specifications which have been recommended are either failures or successes. Any discussion or general comment on the part of the general public will be of valuable assistance to the committee in determining its next move as to advancing an acceptable specification to the interested industries.

It will readily be seen that it would be impossible to fabricate oils for these tests which would meet the maximum specifications in every particular. Therefore the committee decided that the governing limit should be the maximum viscosity specification—200 sec. Saybolt Universal at 100 deg. fahr. for heavy-duty engines and 100 sec. for the light high-speed units. The other qualities of the oil were allowed to fall where they would. For instance, various samples at the maximum viscosity had carbon and ash contents in excess of the committee's recommendation. Members of the committee from the oil industry advised that it would be practically impossible to guarantee the Conradson carbon content in oils of this viscosity at the specified maximum of

[1] Presented at the Oil and Gas Power session at the Annual Meeting, December 2 to 6, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[2] The personnel of this committee is as follows:

Henry C. Dinger, Capt., *Chairman*, in charge of Engineering Experiment Station, U. S. Navy, Annapolis, Md.

Wiley H. Butler, *Secretary*, Standard Oil Company of New Jersey, New York, N. Y.

James C. Barnaby, Assistant to Chief Engineer, Worthington Pump and Machinery Corporation, New York, N. Y.

R. J. Broege, Buda Company, Harvey, Ill.

Harte Cooke, Engineer, McIntosh & Seymour Corporation, Auburn, N. Y.

Thomas G. Delbridge, Supervisor, Process Division, Atlantic Refining Company, Philadelphia, Pa.

Herbert W. Dow, Sales Engineer, Nordberg Manufacturing Company, Milwaukee, Wis.

Louis R. Ford, Consulting Engineer, Brooklyn, N. Y.

H. E. Gehres, Vice-President and Chief Engineer, Cooper-Bessemer Corporation, Mt. Vernon, Ohio.

Lester M. Goldsmith, Consulting Engineer, Atlantic Refining Company, Philadelphia, Pa.

H. C. Hallings, United States Representative, Burmeister & Wain Ltd. (Copenhagen), New York, N. Y.

Charles B. Jahnke, Chief Engineer, Fairbanks, Morse & Co., Beloit, Wis.

Charles Legrand, Consulting Engineer, Phelps-Dodge Corporation, Douglas, Ariz.

Kenneth G. MacKenzie, Chief Chemist, Texas Company, New York, N. Y.

John T. McCoy, Assistant Technologist, Tidewater Oil Company, Bayonne, N. J.

Lester G. Metcalf, Assistant Manager of Refineries, Union Oil Company of California, Los Angeles, Calif.

B. E. Meurk, Superintendent Engineer, Isthmian Steamship Lines, New York, N. Y.

G. H. Michler, Standard Oil Company of New Jersey, New York, N. Y.

Ernest Nibbs, Chief Engineer, Electric Boat Company, Groton, Conn.

Ralph Miller, Chief Engineer, Oil Engine Department, Ingersoll-Rand Company, Phillipsburg, N. J.

M. J. Reed, Research Engineer, Diesel Engine Manufacturers Association, New York, N. Y.

Lee Schneitter, Plant Betterment Engineer, Electric Bond and Share Company, New York, N. Y.

Benjamin C. Smith, President, Standard Motors Construction Company, Jersey City, N. J.

George N. Somerville, Atlas-Imperial Diesel Engine Company, Oakland, Calif.

4 per cent. Consequently, it was deemed advisable to procure as much information as possible with fuels at 200 sec. viscosity and note the difference, if any, between the product falling within the Conradson specification and that which did not.

Manufacturer No. 1. Oil submitted in this case was made up under the following analysis:

A.P.I. gravity	23.0 deg.
Flash point (closed cup)	210° F.
Viscosity at 100° F. (Saybolt Universal)	200 sec.
Sulphur (bomb)	1.144%
Pour	Zero and lower
Ash	Trace
Moisture	None
B. S.	0.05%
Conradson carbon	3.33%

This manufacturer has not had an opportunity as yet to conduct a thorough test, but during a preliminary run on his 11-in. by 14-in. engine he found that the load could be maintained only by dropping the speed from the standard 350 r.p.m. to 325 r.p.m. At this condition the exhaust contained a considerable amount of smoke. This manufacturer hopes to present a more conclusive report in the very near future.

Manufacturer No. 2. This manufacturer has not yet had an opportunity to test the sample of heavy fuel which he obtained, but expects to be able to report in the very near future.

Manufacturer No. 3. Oil tested by this manufacturer had the following analysis:

Viscosity at 100° F. (Saybolt Universal)	193 sec.
Sulphur	1.543%
Conradson carbon	5.76%
Ash	0.042%
Flash point (closed cup)	210° F.
Moisture and sediment	0.05%
A.P.I. gravity	22.1 deg.

The engine used for the test had the following characteristics:

Cycle	Four
Acting	Single
Number of cylinders	Two
Bore	12½ in.
Stroke	18 in.
Rate of speed	280 r.p.m.
Brake horsepower	115 b.hp.
Piston cooling	None
Type of spray valve	Multihole nozzle
Condition	100%
Compression pressure	380 lb.
Timing	28 deg. before top center to 8 deg. after top center

Two series of tests were conducted, one with standard uncooled spray nozzles and one with water-cooled spray nozzles. In each case the engine was calibrated by running a preliminary test on a light fuel oil of 28 deg. B. and low viscosity. The tests run using the sample oil and the uncooled nozzles showed very little difference from the performance on the light oil at the start. In each case, however, after the engine ran for about 1½ hours the exhaust became quite smoky and the engine had to be shut down to clean the spray nozzles. Until this happened, however, the fuel consumption, exhaust temperature, and the appearance of the exhaust were about equal to the corresponding performance on light fuel at loads from 25 to 110 per cent of rating.

When using the cooled nozzles the performance was again practically the same with the sample oil as with the light oil. The trouble with smoking after a period of running, however, was not so serious. An analysis of this smoking trouble showed that the injection nozzles were being fouled with the formation of small carbon craters. This formation in the case of the uncooled nozzles was more serious than in the case of the cooled nozzles. In the latter instance the cone seemed to form to a certain point and then break off to pass out the exhaust.

After the tests were completed, the engine was run with cooled nozzles at shop load until the balance of the fuel was consumed. During this time the performance was as good as with the light fuel with the exception that considerable trouble was once experienced in starting with the outside temperature at 45 deg. and a certain amount of difficulty at starting was experienced every day, although this difficulty was only slight.

It was the manufacturer's opinion that the extent to which these objectionable carbon cones were formed is not sufficiently serious to call the fuel unsatisfactory, and he felt that perhaps improvement in design might entirely get rid of this cone-forming feature in the near future.

Manufacturer No. 4. Oil tested by this manufacturer had the following analysis:

Viscosity at 100° F. (Saybolt Universal)	193 sec.
Sulphur	1.543%
Conradson carbon	5.76%
Ash	0.042%
Flash point (closed cup)	210° F.
Sediment and moisture	0.05%
A.P.I. gravity	22.1 deg.

The engine used for this test was as follows:

Cycle	Two
Acting	Single
Number of cylinders	One
Bore	14 in.
Stroke	17 in.
Rate of speed	257 r.p.m.
Brake horsepower	65 b.hp.
Piston cooling	None
Type of spray valve	Uncooled
Type of injection	Precombustion or direct

The engine used is an experimental engine which can be arranged to operate with a precombustion chamber or with injection directly into the main combustion chamber. Tests using the sample oil were conducted for either system of injection, and results were noted at full, three-quarter, half, and no-load.

Before the runs on sample oil the engine was operated on the light fuel oil used for shop testing. The results indicated that the engine was in first-class condition.

The sample oil runs with the engine arranged with a precombustion chamber showed exhaust temperatures approximately 15 deg. higher than on the shop oil. The exhaust was dark and cloudy, all of which indicated incomplete combustion and fuel consumption considerably increased.

The sample-oil runs with direct injection showed exhaust temperatures approximately 15 deg. higher than with shop-test oil, indicating a tendency toward incomplete combustion. The exhaust was cloudy.

An examination of the engine after running with precombustion showed carbon deposits on the nozzle and cylinder head. After running on direct injection, a crater was found around the nozzle orifice, and the top of the piston was found to be covered with soft, fluffy carbon. The engine could not be started from cold, using the sample oil with either system of injection, but had to be first warmed up on light oil.

This company concludes that the sample oil is unsatisfactory for general use in Diesel engines of this type because of its high viscosity and low gravity.

Manufacturer No. 5. Oil used for this test had the following analysis:

Ash	0.36%
Water	0.50%
Sediment	0.11%
Sulphur	2.36%
B.t.u. (high)	18,520
Baumé (60° F.)	15 deg.
Flash point (p.m. closed cup)	270° F.
Fire point (open cup)	329° F.
Conradson carbon	3.90%
Viscosity at 100° F. (Universal)	198 sec.

The engine used for this test was as follows:

Cycle	Four
Acting	Single
Number of cylinders	Four
Bore	14½ in.
Stroke	18 in.
Rate of speed	277 r.p.m.
Brake horsepower	260 b.hp.
Type of spray valve	Solid injection; Price system; single orifice, uncooled
Condition	New engine
Compression pressure	340 lb.

The engine was first operated for 4½ hours under full-load conditions with fuel temperature at 81 deg. fahr. The exhaust was light brown, slightly darker than the previous run with shop-test oil. The engine was then operated for 2½ hours at 18 per cent of full load. The exhaust during this light-load operation showed a very dense, yellowish smoke. Quite frequently fuel charges failed to fire in the engine, causing unsteady operation. After this test full load was again applied, and after a few minutes of full-load operation the previous full-load conditions were re-established. The oil was then heated from 81 deg. fahr. to 141 deg. fahr., but no changes were noted in the operation at full load. Furthermore, with heated fuel, the light-load operation was no less erratic.

Manufacturer No. 6. Oil tested by this manufacturer had the following analysis:

A.P.I. gravity	14.7 deg.
B.t.u.	18,565
Viscosity at 100° F. (Saybolt Universal)	178 sec.
Sulphur	0.931%
Conradson carbon	6.0%
Water and sediment	0.9%
Ash	Trace

The engine used by this manufacturer in this test had the following characteristics:

Cycle	Four
Acting	Single
Number of cylinders	One
Bore	17 in.
Stroke	19 in.
Rate of speed	257 r.p.m.
Brake horsepower	110 b.hp.
Type of spray valve	Single orifice; double check, uncooled, Price system
Condition	New engine
Compression pressure	335 lb.
Timing	21 deg. before top center

This engine was operated on the sample oil for 2½ hours at loads from 25 to 110 per cent of rating. The fuel oil was consumed more efficiently at 100 and 110 per cent loads than on the shop-test oil, but considerably less efficiently at loads from 25 to 75 per cent. The exhaust on the sample oil was quite smoky in comparison with the shop-test oil. After the run the engine was examined, and the exhaust valve, seat, and stem were found to be gummed. There were also gummy deposits of carbon in the exhaust manifold. The temperature of the sample oil at the engine was 70 deg. fahr., but no trouble was experienced in starting.

The opinion of the manufacturer was that the sample oil was unsatisfactory for this type of engine in view of the very poor performance at low load.

Naval Experimental Station, No. 7. Operating tests of a special Diesel oil were conducted at this station in connection with the standardization of Diesel fuel-oil specifications. The analysis of the special Diesel oil was as follows:

A.P.I. gravity	20.8 deg.
Flash point (closed cup)	200° F.
Sulphur content	1.45%
Conradson carbon	5.41%
Ash	0.1%
Sediment	0.21%
Viscosity at 100° F. (Saybolt Universal)	200 sec.

The M.A.N. engine of 350 hp. was run 72 hours at 100 per cent load and operated very satisfactorily when the oil was heated to at least 145 deg. fahr. Attempts to start this engine with the oil at room temperature of about 60 deg. fahr. were unsuccessful. The operation of the engine with the oil below 145 deg. fahr., after the engine had been started by other oil, was not satisfactory. It was found advisable to have the heater within a few feet of the fuel-metering cylinder. The apparent difficulty in using this Diesel oil seems to be in the flow to the fuel pump through the metering chamber. The design of the M.A.N. engine, with a small metering chamber, greatly restricted openings to the fuel pump, and pump plunger of ⅜ in. diameter by 1-in. stroke does not allow the use of the more viscous fuel. It is believed, however, that after the fuel is delivered by the pump at high pressure to the cylinder and vaporized by the means of high-pressure air, the actual combustion of the more viscous fuel is nearly equal to that of the present Navy standard Diesel oil. This engine operates very satisfactorily on Navy Diesel fuel without any heating. It also operated on Bunker "A" fuel that has been centrifuged and heated to about 140 deg. fahr. This engine, built in Germany 11 years ago, has very small and intricate oil passages. It is necessary that the fuel be fluid enough to flow readily through these passages. Apparently if the oil is heated to between 3 and 4 Engler (approximately 90 to 130 Saybolt Universal), which corresponds to 130 deg. fahr. for the A.S.M.E. standard Diesel fuel, the oil will function with apparent satisfaction.

The Fairbanks-Morse 50-kw. engine was run 48 hours at 35 hp. with this special fuel at 60 deg. fahr. However, due to the fact that less viscous fuel is handled more easily by the service pump, the operation of the engine was more satisfactory and reliable with fuel at 120 deg. fahr. The Fairbanks-Morse engine is of the semi-Diesel solid-injection type previously made by the manufacturer and is more likely to give inefficient results when using the heavier fuel, due to the fact that the compression pressure above the piston and the corresponding temperature are not as high as with the full-Diesel-type engine. In addition, the solid injection of fuel at a considerably lower pressure does not tend to give as complete vaporization of the fuel as obtained in the full-Diesel engine. This engine can be operated on A.S.M.E. standard fuel, but it will give more satisfactory operation on Navy Diesel, which is the oil ordinarily used. However, this engine also will operate on Bunker "A" when heated to 140 deg. fahr.

The Nelseco 150-kw. Diesel engine was run 36 hours at 85 hp. and operated very satisfactorily with this special fuel, starting and operating very well at room temperature of 58 deg. fahr. The design of the Nelseco Diesel engine is such that a more

viscous oil can be used. The engine has large fuel lines to the fuel metering chamber, and a fuel pump with plunger $^5/_8$ in. diameter by $^3/_8$ in. stroke, in connection with high-pressure air atomization. The standard A.S.M.E. fuel appears to function about as well as Navy Diesel in this engine.

The Cummins (motor boat) 50-hp. Diesel engine is a six-cylinder, four-cycle, full-Diesel solid-injection engine, rated at 50 b.hp. at 850 r.p.m., for use in driving motor boats. While the time of running the special Diesel oil in this engine was only one hour, it was determined that the engine would start and operate satisfactorily with the special Diesel oil at ordinary room temperature of about 70 deg. fahr., although when load was put on, the exhaust was somewhat smoky. It is believed that with the installation of a heater, using circulating water to heat oil to about 130 deg. fahr., this engine would operate in a generally satisfactory manner. A lighter oil would of course be somewhat better, especially for starting or for operating in cold weather.

From the short trials on Diesel engines at the Experiment Station, the indications are that proper fluidity is the essential matter, and then when this is obtained by heating, much heavier fuel can be used on the small engines than is generally supposed. The difficulty with heavy oil seems to be largely due to failure of the oil to flow properly through the small passages that are met with on some engines.

The determination of the proper temperature to which to heat Diesel fuel is as follows:

It has come to the notice of this station that the M.A.N. engineers have recommended that Diesel fuel be brought to the proper liquid state by heating so that the viscosity at the atomizing nozzle is brought to about 5 deg. Engler (approximately 170 Saybolt Universal). This information seems to be more or less substantiated by the experience in heating Diesel fuel for the various engines at this station. The following comment in regard to this matter may suggest a field of investigation:

The proper viscosity at the oil pump is a very important matter in proper operation of Diesel engines. From a limited number of runs at the Experimental Station on four engines—the M.A.N. German submarine 250 kw., Nelson four-cycle 100 kw., Fairbanks-Morse 50 kw., and Cummins solid injection—it would appear that the viscosity at the pumps should be approximately 4 Engler (approximately 130 Saybolt Universal).

Light oils such as Navy Diesel require no heating even in cold weather. In this case 4 Engler (approximately 130 Saybolt Universal) corresponds to about 45 deg. fahr. However, the design of the oil passages will affect the ability of the engine to operate.

The A.S.M.E. committee's sample Diesel fuel will work on most American engines without heating, but in engines of German design a more fluid oil is necessary. Apparently impossible oils if heated to 4 Engler will operate on most any engine. The fact is significant that the Cummins 50-hp. 850-r.p.m. solid-injection will operate on the sample fuel without heating, while the M.A.N. 350-hp. will not. Additional experiments should be made by engine builders in an effort to establish the proper viscosity Saybolt at which any Diesel gives complete satisfaction. In the case of mechanical oil-burning apparatus this has been found to be 2 to 4 Engler (approximately 50 to 130 Saybolt Universal). It is probably near the same point for Diesel engines.

If there could be obtained the results of tests on heavy Diesel fuel heated to a temperature at which it gives satisfaction, this point could be determined for practical purposes.

It is suggested that builders and users be asked to make such tests and to report the temperature at which fuels seem to give most satisfaction.

Light Oil Specifications

The committee has been concentrating on the specification for heavy-duty oils and has this work well under way. It is now making arrangements to test the oils meeting the tentative specification for light high-speed engines. The oil companies which are represented on this committee will be in a position to supply fuels in order that these tests might be conducted. Consequently, it is requested that the engine builders that are producing motors of the aforementioned type procure sufficient quantities of this oil to conduct tests in a manner similar to those that have been made with the heavier oil and to advise the committee of the results. Several builders of light Diesels have already received samples, but information on the tests has not been submitted.

Conclusion

Although the results so far disclosed on the proposed specification for Diesel have not given entire satisfaction in some medium-sized engines when the oil was not heated at the fuel pump, the committee is not inclined to accept those results as final and will modify the specification. As the purpose in establishing a Diesel fuel for general distribution is a question of price and as any change would stipulate a lower viscosity or a more stringent Conradson, it would materially increase the cost of such a product. The work will be carried on in testing the present specification oil, but the committee is also planning to supply some manufacturers with oils with viscosity of approximately 150 and 125 sec. Saybolt Universal at 100 deg. fahr. In doing this, naturally the Conradson carbon would be decreased, and it is hoped to be able to have available oils with a carbon content of maximum 4 per cent and possible 3 per cent. This might avoid the carbon deposits which have been mentioned in some of the test data.

It is desired to state that the data herein reported are only preliminary, giving the operating results on the sample fuel sent out, and will serve to indicate generally how the specification fuel will operate when unheated. This and future reports will also indicate to what extent difficulties may be overcome by heating or other possible methods of handling the fuel.

The committee wants to take this opportunity to thank the oil industry and the Diesel-engine manufacturers for their wholehearted cooperation in furthering this work.

Discussion

Edgar J. Kates.[3] The committee is to be congratulated upon the important and very practical start it has made in determining the significance of the various oil characteristics by direct experiments on actual engines. The reports of these tests should be of invaluable assistance in clearing up some of the mystifying questions that have hitherto delayed a solution of this problem.

Presumably the test reports will receive careful interpretation by the committee and full consideration will be given to all factors. For instance, in one or two cases the reports indicated that the engines performed satisfactorily upon the A.S.M.E. special oil when running under normal load, but that there was trouble with irregular operation and misfiring when running at light load. In view of the fact that other engines do not give such trouble when running on the same oil, the committee should determine whether the trouble is with the oil or with those particular makes of engine. There are certain engines on the market in which the fuel-injection and combustion systems are such that irregular operation at light load is characteristic even with fuels of the highest quality. It behooves the manufacturers of those engines to improve their designs to eliminate this trouble rather than to blame the oil.

[3] Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

The tests reported were of comparatively short duration, ranging from a couple of hours to 72 hours. For this reason the tests can hardly show the effects of all of the properties of the fuel oil, since the results of sulphur and ash would certainly not become apparent in so short a time. The tests indicate something about the effects of viscosity and Conradson carbon, but of course it will be necessary to have many more reports before any positive conclusions can be drawn.

It is to be hoped that the engine builders will continue to cooperate fully in this exceedingly important investigation.

Results of Further Field Tests on Suggested Diesel Fuel-Oil Specifications[1]

Progress Report No. 3 of the A.S.M.E. Special Research Committee on Diesel Fuel-Oil Specifications[2]

DURING the winter meeting of The American Society of Mechanical Engineers in New York, this committee presented a Progress Report. This report was mostly upon the results of various tests conducted by Diesel-engine manufacturers on the fuel designated as tentative standard specifications. It will be remembered that a great many of these tests showed unsatisfactory operation by a number of the engines when operating on the oil specified for heavy-duty engines with a maximum viscosity of 200 sec. In most cases, in meeting the viscosity specification, the various oil companies had a Conradson carbon content in excess of the suggested maximum of 4 per cent, and the difficulties encountered in operating these engines were due to carbon formation, incomplete combustion, and erratic operation, expecially at low load. Consequently the committee should turn its attention to the question of Conradson carbon and fluidity. If, as was pointed out in the second Progress Report, Conradson carbon in excess of the maximum could be employed and the oils be reduced in viscosity by applying heat to give the necessary fluidity, it is felt that satisfactory operation might be had. If the results are not as expected and the operation is unsatisfactory with the fluid oil, then the logical step would be to lower the Conradson carbon. The oil men on the committee have advised that if such a procedure is necessary, the viscosity will automatically be decreased and the general characteristics of the oil will all be improved, with the natural result of a more expensive oil to the consumer. Naturally it is the desire of this committee to standardize on the cheapest satisfactory oil which is available.

The committee requested the industry, through the medium of its last report, to conduct tests. In answer to this it received some very interesting data from the Florida Power and Light Company in which this company states that it has conducted some tests and has successfully burned fuel oil with a viscosity of 116 sec. at 122 deg. fahr. (Saybolt furol), which is approximately six times the viscosity recommended by this committee on the Universal scale. This oil has a Conradson carbon content of 10.07 per cent and about 15 gravity. It has been found that the oil could be satisfactorily burned in continuous operation with an average load factor of approximately 90 per cent when a temperature of approximately 125 deg. fahr. is maintained at the fuel-injection valve. Of course, this engine is a large and slow-moving two-cycle air-injection engine.

On the other hand, a report has been passed on to this committee in which a 17 by 24 four-cycle solid-injection engine turning at 231 r.p.m. successfully handled 12–14 A.P.I. boiler oil. The oil is heated to approximately 200 deg. fahr. and flows through a jacketed line to the pumps. The report states that the engine can be operated from no load to 30 per cent overload and the exhaust be practically invisible. When an inspection had been made, there was no evidence of carbon formation, and the exhaust valve remained in service the length of time equivalent to operation of light fuels.

One manufacturer has reported to the committee that his engine would not operate satisfactorily on the A.S.M.E. Diesel fuel. Consequently, he has redesigned his fuel system and now reports that this type of engine will successfully operate on fuels of this nature, with the following reservations:

1 Provisions be made to preheat the fuel to approximately 150 deg. fahr.

2 Provisions be made to start and stop the engine on a lighter approved fuel.

3 That the engine is not required to run at light loads, 25 per cent or less, for extended periods.

The oil supplied this manufacturer had a viscosity of 200 sec. and a Conradson carbon content of 5.17 per cent; but in concluding his report he writes as follows:

"From the foregoing it can readily be seen that we need a fuel oil of lower viscosity that will not require special means of heating between supply and nozzle and which can be used for cold starting."

Still another manufacturer of solid-injection engines reports to the committee that after having conducted tests on a fuel of 175 viscosity and Conradson of 3.9 per cent, the exhaust at full load

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[1] Presented at the Meeting of the Oil and Gas Power Division at Pennsylvania State College, State College, Pa., June 12, 1930.

[2] The personnel of this committee is as follows:

L. H. Morrison, *Chairman*, Associate Editor, *Power*, McGraw-Hill Publishing Company, New York, N. Y.

W. H. Butler, *Secretary*, Standard Oil Company of New Jersey, New York, N. Y.

J. C. Barnaby, Assistant to Chief Engineer, Worthington Pump and Machinery Corporation, New York, N. Y.

R. J. Broege, Buda Company, Chicago, Ill.

H. Cooke, Engineer, McIntosh & Seymour Corporation, Auburn, N. Y.

T. G. Delbridge, Supervisor, Process Division, Atlantic Refining Company, Philadelphia, Pa.

H. W. Dow, Sales Engineer, Nordberg Manufacturing Company, Milwaukee, Wis.

L. R. Ford, Consulting Engineer, Brooklyn. N. Y.

H. E. Gehres, Vice-President and Chief Engineer, Cooper-Bessemer Corporation, Mt. Vernon, Ohio.

L. M. Goldsmith, Consulting Engineer, Atlantic Refining Company, Philadelphia, Pa.

H. C. Hallings, United States Representative, Burmeister & Wain Ltd., New York, N. Y.

C. B. Jahnke, Chief Engineer, Fairbanks, Morse & Co., Beloit, Wis.

C. Legrand, Consulting Engineer, Phelps-Dodge Corporation, Clifton, Ariz.

K. G. MacKenzie, Chief Chemist, Texas Company, New York, N. Y.

J. T. McCoy, Assistant Technologist, Tidewater Oil Company, Bayonne, N. J.

L. G. Metcalf, Assistant Manager of Refineries, Union Oil Company of California, Los Angeles, Calif.

B. E. Meurk, Superintendent Engineer, Isthmian Steamship Lines, New York, N. Y.

G. H. Michler, L'Economique Oil Company, Paris, France.

E. Nibbs, Chief Engineer, Electric Boat Company, Groton, Conn.

R. Miller, Chief Engineer, Oil Engine Department, Ingersoll-Rand Company, Phillipsburg, N. J.

M. J. Reed, Research Engineer, Diesel Engine Manufacturers Association, New York, N. Y.

L. Schneitter, Plant Betterment Engineer, Electric Bond and Share Company, New York, N. Y.

B. C. Smith, President, Standard Motors Construction Company, Jersey City, N. J.

G. N. Somerville, Atlas-Imperial Diesel Engine Company, Oakland, Calif.

was smoky with high gas temperatures, while at three-quarters and one-half loads the exhaust was clear, with normal temperatures. In quoting the following it more or less substantiates the committee's opinion that the manufacturers of Diesel engines can do much along the lines of design in making this fuel successful.

"All of this is due, no doubt, to the fact that our injection nozzle did not handle the heavier fuel in such a manner as to give the proper atomization and penetration. The test, however, did not result in any carbon deposits on the heads and pistons. Inspection after running on this fuel showed all working parts and filters to be clean.

"Our observation would be that while the engine was capable of handling the fuel, we would not consider this oil as a satisfactory product for normal operation."

The same condition exists as when the committee published its previous results. There is inconsistency in the operation of these various engines, and there seem to be but the two alternative plans. One of them is that the manufacturers of Diesel engines redesign their fuel system and install preheating equipment; but this is practically eliminated, as most of these concerns that have conducted tests have made it plain that they do not wish to operate engines in the field on an oil of these characteristics, and but one manufacturer has shown any desire to reconstruct his motor so that it will satisfactorily burn these fuels. Consequently, but the one alternative is left to the committee, and that is to improve the quality of the oil by lowering the viscosity and simultaneously the Conradson carbon, which will materially increase the price differential between steam-generating oils and Diesel fuel. Comments would be welcomed from the industry upon such a move by this committee.

Light High-Speed Diesel Tests. One of the members of this committee, being a manufacturer of this type of Diesel engine, has conducted a series of very interesting tests on a small four-cycle four-cylinder 7 by $8^1/_2$ solid-injection 80-hp. Diesel engine operating at 650 r.p.m. The first oil was a product of 44 viscosity Saybolt Universal at 100 and a Conradson carbon of 0.48 per cent. The rest of the analysis indicated a distillate fuel. The exhaust was clear, and fuel consumption was normal through full load to half load. The engine started cold. Comment by the test engineer was that the fuel was considered fairly satisfactory.

The next sample was 48 viscosity Saybolt Universal at 100, and Conradson of 1.6 per cent. The exhaust showed a trace of smoke. Fuel consumption was above normal.

The third test was on a fuel of 73 viscosity Saybolt Universal and a Conradson carbon content of 3 per cent. The load dropped off at the specified r.p.m., and the exhaust was slightly cloudy at all loads and the fuel consumption between 124 and 144 per cent normal. When the engine was shut down and left overnight, it failed to start, and when the injection valves were inspected, the tips were covered with a tarry deposit. After cleaning the valves, considerable trouble was encountered in the starting. Even then it took 20 minutes to bring the engine to full-load capacity. In the engineer's opinion the heavy deposit left in the cylinders renders the oil unsatisfactory for this engine.

Another oil was tested, meeting the maximum A.S.M.E. viscosity specification on this grade of 100 sec. Saybolt Universal at 100 deg. fahr. The Conradson carbon of this product was 3.5 per cent. Fuel consumption was high and the power rating low. The exhaust-intake valves were coated with a gummy substance and had to be cleaned before the engine could be started. After considerable difficulty the engine was started and required 30 minutes of idling before any load could be applied. During operation it was necessary for the staff constantly to apply penetrating oil to the valve stem to keep the valves free. After running 15 minutes it was necessary to stop and clean the injection valve. The r.p.m. constantly decreased during operation. Commenting on this oil, the engineer advises that during this test the exhaust was clearer than any of the oils tested, but the power was much lower, and considerable trouble was encountered and heavy deposits of pitch were left in the cylinder.

In analyzing these results it is apparent that Conradson carbon in excess of 1 per cent is unsatisfactory for the operation of motors of this size and speed. The committee has requested that this manufacturer blend sufficient quantities of the first-mentioned oil having a Conradson carbon content of 0.48 per cent with the second grade having a Conradson of 1.6 per cent, in such quantities that the carbon content will be slightly below 1 per cent; then test this oil under similar conditions and advise of the result. It is believed that these data should be of considerable interest even though the viscosity will be considerably below the maximum set by this committee.

One other concern interested in motors of this type advises that, in field operation with motors widely distributed throughout North and South America, the best results are obtained with oils running between 40 and 60 sec. Saybolt Universal at 100, and trouble has been experienced when using oils in excess of 70 sec. Consequently, it feels that 100 sec. Saybolt Universal would not be satisfactory for its engines. With reference to Conradson carbon, this concern states that it has operated engines successfully on quantities as high as $2^1/_2$ per cent, but this is with California Diesel fuel, which, as all know, is of entirely different characteristics from the average fuels east of the Rocky Mountains. Consequently, it is thought safe to say that the 1 per cent is considered satisfactory for them. The other figures specified are felt to be in line with its experience.

In light of these data it does not appear as though this specification would have to be modified to any great extent, although it is self-evident that the viscosity specification will have to be lowered in order that it might conform more closely with actual requirements.

Conclusion. The committee has now arrived at the turning point in the road where it becomes necessary to make a decision on the future policy in this work. One turning will take it into studies to discover the cheapest oil which can be utilized in present Diesel engines. Apparently, if this is the goal, it will have to modify these specifications, perhaps in both classes of engines. The other turning will mean a search for the best compromise between boiler oil and the present cheapest oil which can be used in the present design of engines, but this compromise on oil will necessitate a redesign of Diesel machinery in many instances and the application of pre-heat apparatus. The committee feels that a decision between these policies is a matter which is the concern of the conference in general and the Diesel manufacturer in particular. The committee thinks that this conference should not terminate without some decision being made upon this subject, inasmuch as the work of this committee will come to a standstill very shortly unless the future program is further defined.

Discussion

E. T. LARKIN.[3] We are not builders of Diesel engines, although experiments have been conducted by us during the past twelve years; but we have not marketed or sold oil engines, one of the reasons being the unsatisfactory fuel situation. Suitable fuels were not always obtainable, and available fuels varied greatly in characteristics. We have not considered it advisable to place the burden of obtaining satisfactory fuels on our customers, who in some instances are situated where it is difficult for them to secure proper oils. We have found it necessary, even in our de-

[3] Chief Engineer, Sterling Engine Company, Buffalo, N. Y.

velopment work, to have fuels shipped to us because none were available locally.

Our engines would be of a fairly high-speed type in moderate sizes, and conditions require that they be simple and that auxiliaries such as are used for handling heavy oils be eliminated. The engines must be very easily and quickly started, regardless of air temperatures. Many of our engines are used for standby service where instantaneous starting is frequently required for emergency operation. It is absolutely essential for such work that fuel be of such a character that it will flow easily, be clean, be noncorrosive, and free of material which will clog strainer and lines.

The writer believes that engine builders should be concerned in having available fuels approximating certain standard specifications in order that more uniform performance be obtained from their engines.

E. T. Birdsall.[4] Last winter Mr. Cummins ran a Packard car with a Cummins engine from Columbus, Ind., to the New York Auto Show and from New York to Philadelphia. He also drove from Columbus to Daytona Beach. On all these runs he bought ordinary furnace oil and had no difficulty with the running of the engine. It seems that we are getting too finicky about what oil we are compelled to use in these engines. If Mr. Cummins can do it with that engine, it might be well for some of the faint hearts to look into the matter and see how he does it.

At Mr. Cummins' factory they are running the shop Diesel engine on crankcase drainings.

An engine that requires "specification" oil starts out with a sales handicap and a higher fuel cost than is necessary.

H. C. Dinger.[5] The writer's experience has been that most Diesel engines will run on any clean fuel oil if one can get it warm enough. Take a German engine which ordinarily requires a light oil—such engines have been run successfully with bunker oil heated so as to secure proper fluidity.

If an owner has an engine without a heater and it requires a light oil, he has to get that kind of oil or he may install a heater and use a heavier oil. Engines will run quite differently on different oils, and the most suitable oil for one is not always the most suitable for another. It is a question of whether one wants to arrange the engines to suit the oil that is available or how far he wants to go up in price for fuel. If one gets a light enough oil, he may have a satisfactory oil, but a cheaper oil that will not work entirely satisfactorily on some of the engines will work on most of the engines. A great many of the engines can change the design so that a heavier and cheaper oil can be used. The Diesel engine is competing with the other prime movers, and the price of the fuel oil is an important factor. If the Diesel-engine builders make their engines to use an ideal fuel, which is materially more expensive than bunker fuel oil, they will be unable to compete with steam power in many places. Hence the aim of the builders should be to design their engines or install such accessories (heaters, etc.) as will enable their engines to operate on the least expensive oil that may be available. The standard specification fuel oil for heavy and medium engines should therefore be a fairly heavy oil, and not necessarily a fuel oil that will give satisfaction on any Diesel engine. The economic problem is to make the engine to suit the cheap oil rather than to find an ideal fuel oil that will work satisfactorily on any engine. Such an ideal fuel oil would be too expensive for general use.

[4] Engineering and Research Department, Curtiss-Wright Corporation, New York, N. Y.

[5] Officer in Charge, U. S. Naval Experiment Station, Annapolis, Md. Mem. A.S.M.E.

J. B. Frauenfelder.[6] The principal item of criticism advanced by those who advocate steam as against oil engines is fuel cost. They claim the oil engines will never overcome the differential between $1 per barrel boiler or Bunker "C" oil and $2 per barrel Diesel oil. If the oil engine has to survive, not only its initial cost of manufacture must come down, but also fuel cost. This is important, and it is the Diesel industry's battle and not that of the oil man.

It is suggested that this question of fuel specifications be seriously taken up by the Diesel Engine Manufacturers Association and that it establish a line of procedure for an appropriate committee to work on and cooperate with all the other official agencies now engaged in the solution of the problem of fuel specifications standardization.

L. F. Burger.[7] We do not say that the oil proposition is entirely up to the oil company; the engine builder and the oil company must work together. The oil company should get busy and see the engine builder and find out what the latter wants. If the oil companies do not do this, some of the engine builders will have to make their own fuel oil, which can be very easily made and of a very high grade. For instance, rape seed or castor-oil seeds can be grown very easily and a very high grade of oil made therefrom. In that way the engine operators can easily cut out the oil company. Therefore, the writer believes that Mr. Butler should go to work with the engine builders and find out just what is required so that the engine builders will not be working in the dark at all times.

C. L. Cummins.[8] We have been producing small Diesel engines over a period of years and have met many problems arising from the lack of standardization or knowledge of fuel oils.

It is not believed advisable to establish any closely drawn specifications for fuel oils at this time, as the variety of fuel-injection mechanisms in use demands some differences in fuel oils.

However, the establishing of two or three general specifications covering fuel oils would undoubtedly be of immense value, as it would permit the oil companies and users to work more intelligently with one another.

In the thousands of miles which the writer has driven our Diesel car over the country, he has used a variety of fuel oils with entire satisfaction. The most commonly available fuel has been the light gas oils used in oil burners for home heating. These fuels have been generally satisfactory, except that the lighter oils lack sufficient viscosity to properly lubricate the fuel pump and injection mechanism.

It is therefore felt that viscosity is of considerable importance in any specifications for fuel oil, not only for our own engine, but for practically any Diesel engine.

Wiley H. Butler.[9] The writer has worked with you from a committee point of view. He has supplied you with oils of various characteristics. He also has cooperated with you as closely as he could and as his position as secretary of this committee would permit. The oil industry is ready to cooperate. In changing those limits you change the economic status of that oil. When it comes to the type of the engine, that is an entirely different problem. You have got to have light oils. You can run on them, but you will not run on them for any length of time. You will use the distillate oil until the committee can produce the class of oil that will be satisfactory. We are willing to supply samples and are willing to help in any way we can.

[6] J. Barraja-Frauenfelder & Co., Philadelphia, Pa.

[7] International Harvester Company, Chicago, Ill.

[8] Cummins Engine Company, Columbus, Ind.

[9] Standard Oil Company of New Jersey, New York, N. Y.

OGP-52-9

Nitride Hardening of Alloy Steel for Diesel-Engine Use

By C. R. ALDEN,[1] DETROIT, MICH.

In this paper the author discusses metallurgical developments in the nitride hardening of alloy steels and the advantages that may be expected from increased use. With correct analysis of the steel, freedom from distortion in hardening depends upon the operations preceding nitriding. A sequence of operations is given, and nitriding equipment is described. Time necessary to produce and the cost of the nitrided product are given.

IN JUNE, 1913, Adolph Machlet of the American Gas Furnace Company was granted a patent for case-hardening ferrous materials by heating in ammonia at a temperature above 900 deg. fahr. The early process results in an extremely hard non-corrosive case, though it is so thin and brittle, with lack of tenacious bonding between the case and core, that the finished product is not suitable to many mechanical purposes.

At the research facilities of the Krupp Company in Germany under the direction of Doctor Adolph Fry it was determined that aluminum and chromium, alloyed with steel in proper proportion, when treated in an atmosphere nitrogen at the higher temperature of 950 to 1075 deg. fahr., gave to the case a greatly increased depth and sufficient increase in ductility to insure satisfactory bonding between case and core. In the United States much research work has been done by Doctor V. O. Homerberg of the Massachusetts Institute of Technology, consulting engineer for the American licensees.

Definitions

Nitralloy is steel of special analyses for use in the nitriding process. Nitriding is the process by which special steels can be surface hardened at a low temperature by the action of ammonia.

The principal disadvantage of case carburizing and hardening of low-carbon steels is in the difficulties attendant upon heating and quenching the steels after carburizing. The very considerable amount of distortion obtained is an evidence of high internal stresses resulting in a lowering of fatigue resistance, and the checking or cracking of the hardened case, which checks are frequently invisible to the naked eye, would render carburized materials particularly unsuitable for fuel-injection sytem details, even if the process were not ruled out by the low factor of safety incident to the small diameters and thin sections encountered.

For the foregoing reasons both consumers and producers have earnestly sought materials and methods of hardening which would combine the properties of: (1) Extreme surface hardness, (2) resistance to wear, (3) resistance to scoring and abrasion, (4) resistance to corrosion, (5) high physical properties, (6) minimum distortion in hardening, (7) hardness maintained up to high temperatures, (8) machinability, and (9) forgeability.

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Presented at the Third National Oil and Gas Power Meeting, State College, Pa., June 12 to 14, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Analysis of Properties

1 The properly nitrided surface is the hardest known form in which steel may be placed. It will readily scratch glass, and the chart Fig. 1 shows the Brinell hardness in comparison with other steels treated for their maximum hardness.

2 and 3 Resistance to wear would seem naturally to follow extreme hardness, but in addition nitrided surfaces possess a certain resistance to abrasion and scoring under high rubbing pressures and in the absence of lubrication. Only two of many possible examples will be cited:

Valve trimmings consisting of plug and sealing rings for large gate valves operated under high steam pressures with high superheat presented an extremely difficult problem which has been solved by nitrided trimmings.

Fuel-pump plungers and bushings which must work under extremely close clearances in the presence of fuel practically devoid of lubricating qualities have also given much trouble due to scoring, but it seems possible to eliminate this completely by proper application of nitrided materials.

4 The surface resulting from the nitriding process is as stainless as any of the stainless steels, and its combined properties of stainlessness and resistance to wear have proved of value in practically eliminating packing-gland wear on water-pump shafts; however, the stainless properties rapidly decrease if too much of the outer surface of the case is removed by grinding. In most applications of this material the nitrided parts can be produced with sufficient accuracy to require no grinding after nitriding.

Fuel-injection details must be ground and lapped after nitriding; however, with proper precautions, no reports of objectionable reduction of stainless properties have been received.

5 Fig. 2 shows the physical properties of Nitralloy G when tempered at various temperatures together with its analysis. The maximum tensile strength of Nitralloy G is in excess of 220,000 lb.; however, as the temperature at which the material is nitrided is usually close to or slightly in excess of 1000 deg. fahr., the tensile strength in excess of 180,000 lb. cannot be depended upon.

Fig. 3 shows the physical properties of Nitralloy H, which is lower in carbon than Nitralloy G; both steels are claimed to possess unusual resistance to fatigue, which claim seems to be well substantiated by test. One motor-car manufacturer operating in the high-priced field has a fatigue test for crankshafts which consists of locating a center bearing 0.040 in. out of line with the end bearings. Shafts are run to destruction at a fixed speed under this condition.

Breakage of standard shafts occurs in about 75 hr.; nitrided shafts in about 1500 hr. The reason given for the marked difference in results is that the long period during which the material is held at approximately 1000 deg. fahr. during the nitriding operation has a normalizing effect upon the core thoroughly relieving any internal stress which would tend to start fatigue stress failures in service.

6 Due to the sequence of machining and heat-treating operations later to be covered and to the fact that temperatures in the hardening process do not approach the critical temperature

of the material there is very little distortion in hardening. The distortion is so small that for most classes of service parts may be finish-ground to size before hardening.

This property of small distortion in hardening is a decided boon, especially to makers of spiral bevel gears, for which there is no thoroughly satisfactory method of correcting hardening distortion. It is claimed that the most accurate hardened gears have been made of nitrided material, and it is known that both

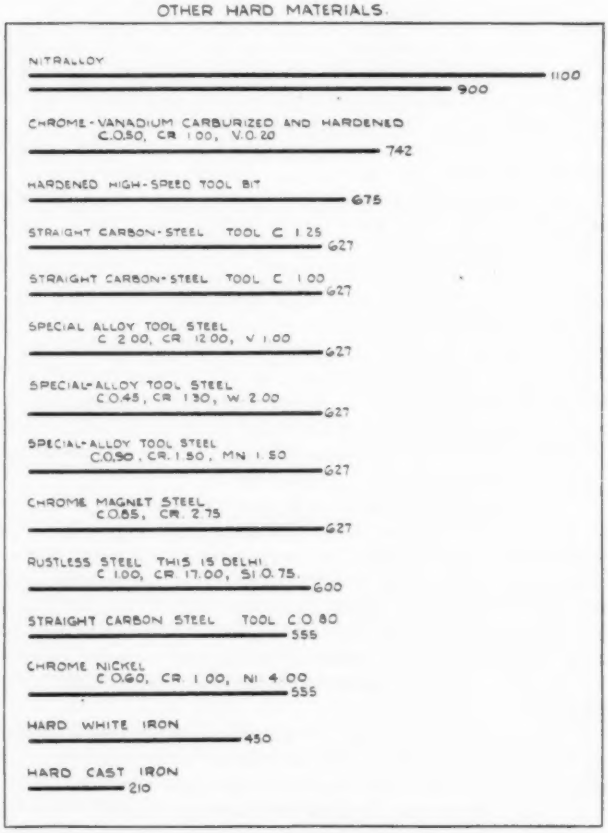


FIG. 1 HARDNESS OF NITRALLOY COMPARED WITH OTHER MATERIALS

accuracy and extreme surface hardness are factors in gear longevity. Nitrided materials, however, have not been recommended for transmission shifting gears as the extremely hard surface is too brittle to withstand the impact incident to improper shifting.

7 The nitrided case suffers no change whatever in hardness at temperatures up to 932 deg. fahr. and does not entirely lose its hardness even when heated to temperatures between 1400 and 1500 deg. fahr., though scaling occurs at the last named temperatures if oxygen is present.

Some applications to valve stems, valve guides, and even valve heads have been made with good success, for in such service lubrication is likely not to be of the best, with a tendency to abrasion under the high temperatures. Nitrided balls have also been used in continuous core ovens and similar applications where high temperatures are encountered.

OPERATIONS PRECEDING NITRIDING

The choice of steel for any given service is made in accordance with the characteristics of the service required. Assuming correct analysis of the steel, freedom from distortion in hardening is altogether dependent upon the operations preceding nitriding, and the preliminary operations can also affect the character of the case.

The sequence of operations in the case of complicated machined sections of articles to be forged is as follows: (1) Forge as S.A.E. steels, (2) heat-treat as per tables for physical properties, (3) rough machine, (4) normalize at drawing temperature four to five hours, (5) finish-machine, grind, and lap, and (6) nitride.

As the material machines more readily before heat treatment for the physicals, it is sometimes desirable to perform a first rough-machining operation between (1) and (2) in the foregoing schedule.

In the case of parts being produced by machining from bar stock, when also no rigid requirements as regards physicals must be met, it is possible to omit some of the foregoing operations; however, in all but the very smallest and simplest sections where great accuracy is not required, the normalizing between rough machining and finish machining is required.

Heat-treated bar stock may be obtained to specifications on mill orders. It is of the utmost importance that all quenched-

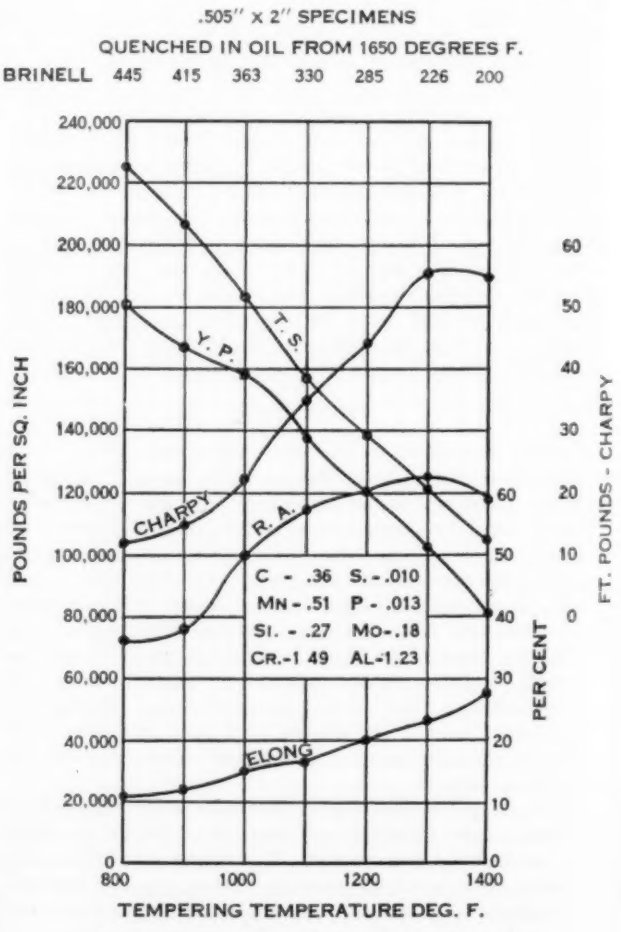


FIG. 2 PHYSICAL PROPERTIES OF NITRALLOY G

and-drawn parts shall be normalized at the drawing temperature; the annealing temperature may be below, but never above the drawing temperature. In the case of parts having to be straightened after rough machining, an additional anneal at 1000 deg. fahr. for four to five hours should always be employed to relieve straightening strains.

Due care should always be exercised in the design and prepa-

ration of parts for nitriding to see that all sharp edges are relieved and suitable fillets are used to avoid chipping of the hardened case at these edges. The removal of all decarburized surface and all scale left from forging or rolling is also imperative as erratic results will certainly be apparent otherwise.

Nitriding and Nitriding Equipment

Parts to be nitrided are placed in a gas-tight box loosely and without any packing material. Sealing may be obtained by a lid clamped on an asbestos gasket or preferably by a positive oil seal. The retort may be heated by electricity, gas, or oil, but the temperature should be under automatic control, as constancy of temperature is important and record of the temperature of the entire run should be kept by a recording pyrometer.

Anhydrous ammonia gas from the conventional steel cylinder is throttled through a suitable pressure-regulating valve, carried through lime to insure removal of moisture, and introduced into the retort through nickel pipes. The outlet gas is passed through apparatus making possible a frequent check on the percentage of dissociation, thence through a wash bottle as a water seal and to the atmosphere as shown in Fig. 4. The per cent dissociation should be maintained between 20 per cent to 40 per cent. Lower dissociation does not harm, but is wasteful of ammonia. Positive circulation of the gas in the retort as by fan is advantageous in securing rapid and uniform results.

In Fig. 5 (*Iron Age*, March 13, 1930, page 787) a large oil-fired box-type furnace is shown having a length capacity of 11 ft. as used by the Camden Forge Company. Fig. 6 (*Iron Age*, March 13, 1930, page 788) shows a large Nitralloy roll for rolling corrugated paper and a Diesel-engine piston rod, both products of this furnace. Numerous other types of furnaces are either on the market or are in process of development. One of particular note is of the continuous-production chain-belt type.

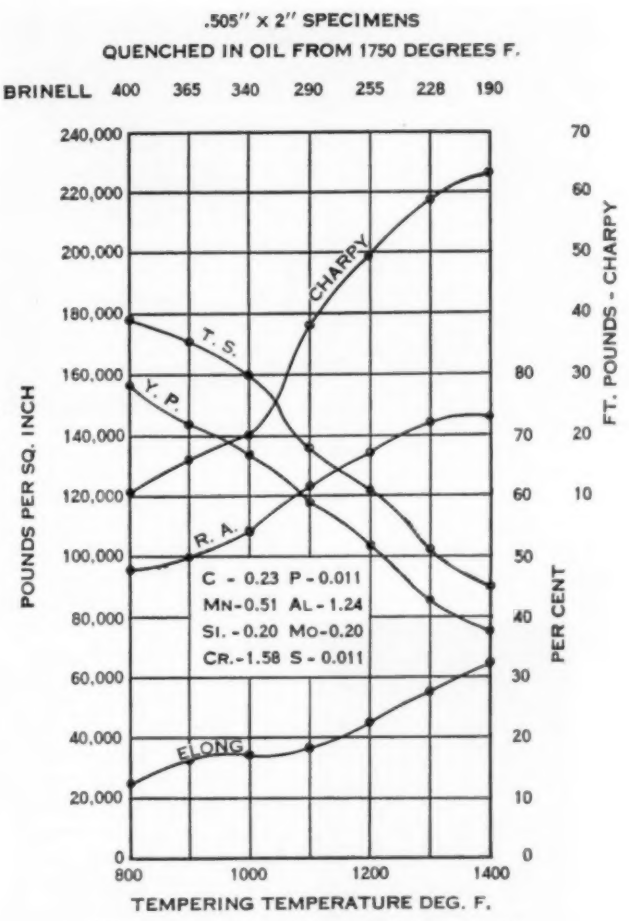


Fig. 3 Physical Properties of Nitralloy H

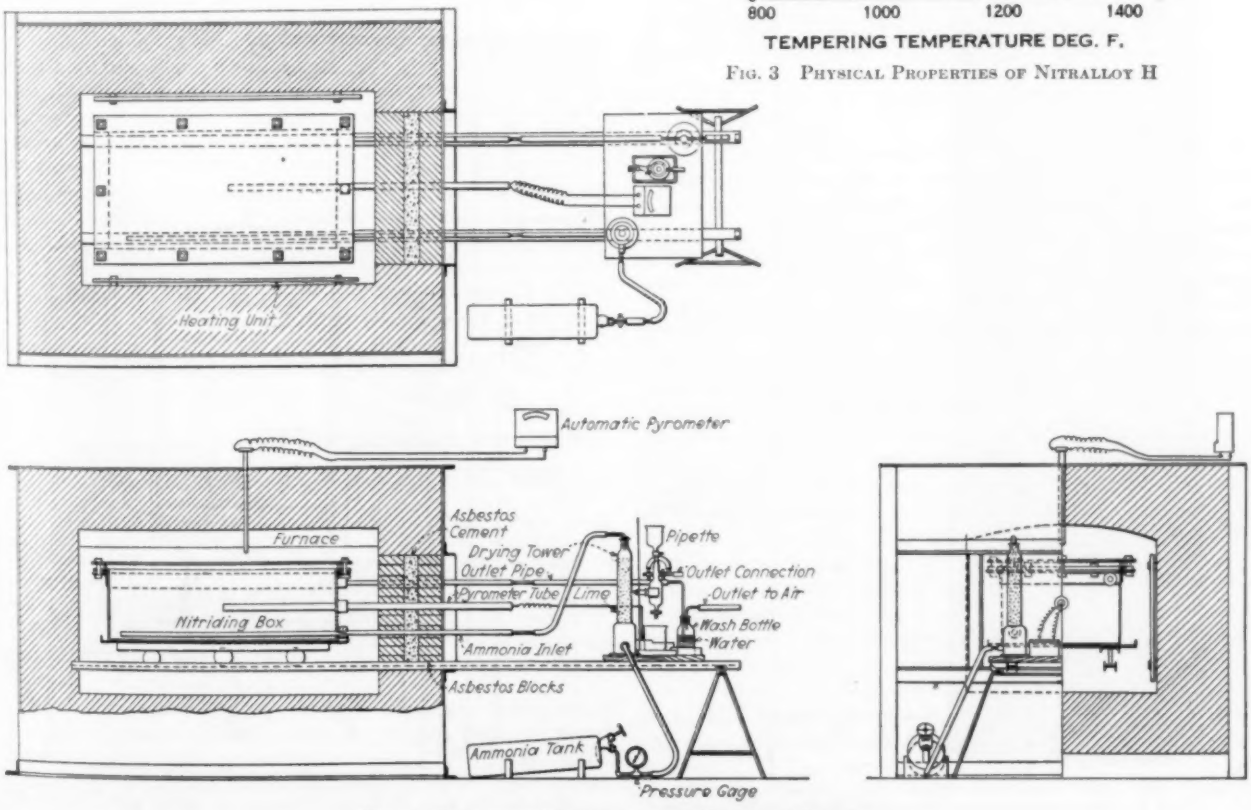


Fig. 4 Schematic Illustration of Nitriding Process

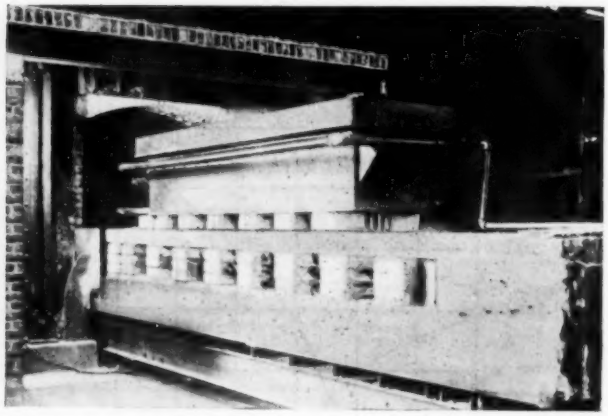


FIG. 5 LARGE OIL-FIRED, BOX-TYPE FURNACE

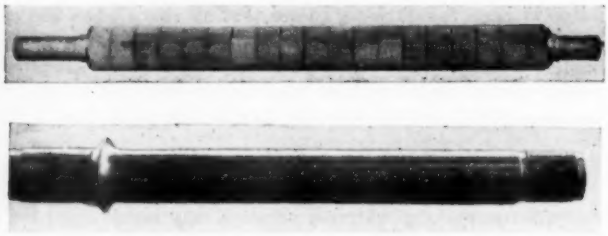


FIG. 6 AT TOP, NITRALLOY ROLL FOR ROLLING CORRUGATED PAPER; AT BOTTOM, DIESEL-ENGINE PISTON ROD

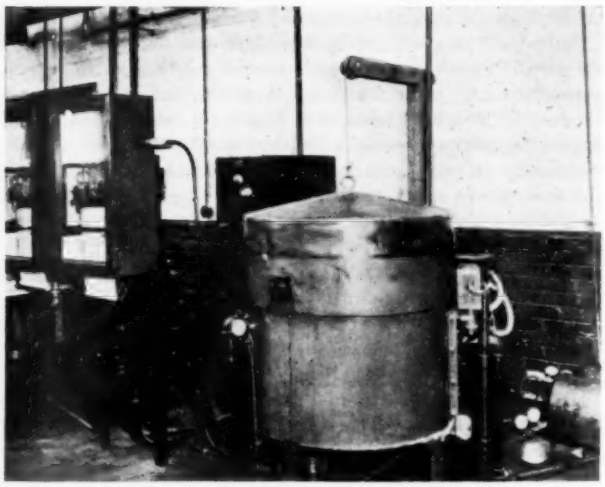


FIG. 8 HOMO FURNACE OF THE LEEDS AND NORTHRUP COMPANY

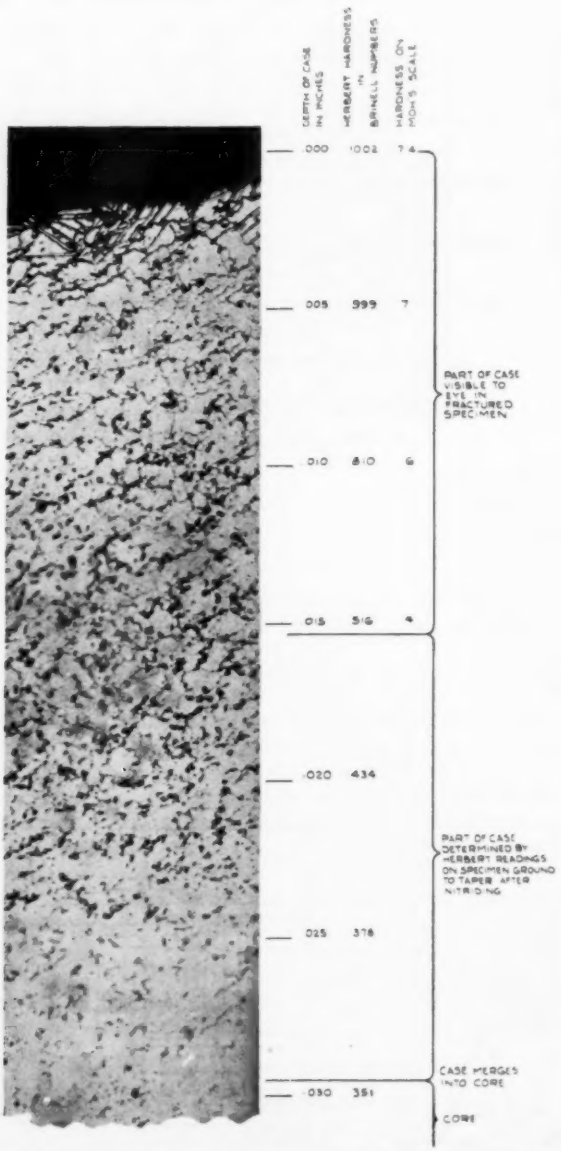


FIG. 7 PHOTOMICROGRAPH SHOWING DEPTH OF HARDNESS OF CASE

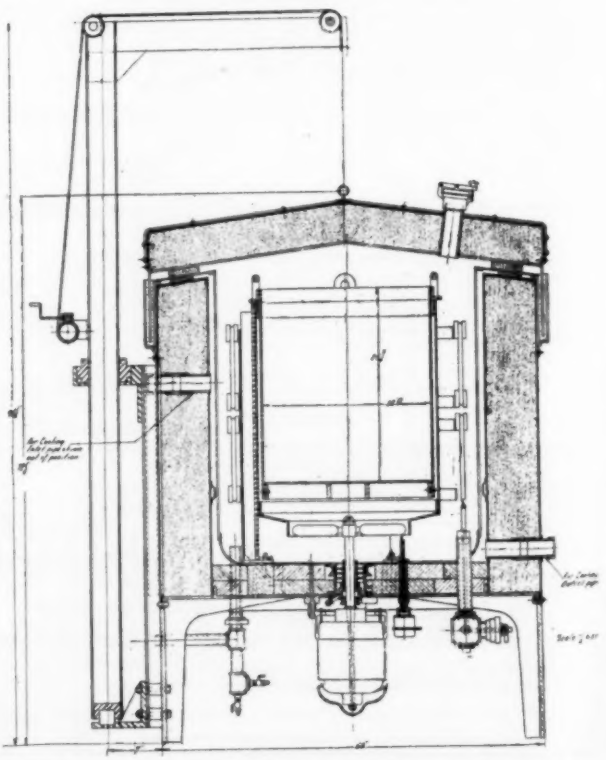


FIG. 9 SECTION OF HOMO FURNACE OF LEEDS AND NORTHRUP COMPANY

Time Required for Nitriding

Both the depth of penetration and the hardness of the nitrided case are affected by the temperature and length of time the material is held at the given temperature in the presence of ammonia. The longer the time and the higher the temperature the greater is the penetration, while higher temperatures do not result in obtaining the maximum hardness of the case.

When first introduced the process was scheduled to be accomplished in 60 to 90 hr. exclusive of heating and cooling time; however, improved materials and equipment are now reducing this time, though a minimum safe figure cannot be quoted as methods are changing rapidly. It is quite conclusively shown, however, that dual-cycle treatment consisting of 950 deg. fahr. for 12 hr. followed by an increase in temperature to 1125 deg. fahr. for 16 hr. is productive of case hardness of 1000 to 1125 Brinell, the high temperature portion of the cycle being for the purpose of increasing the depth more rapidly than could otherwise be accomplished. Combination cycles still further reducing this time are being talked of, but are not proved.

Cost of the Nitrided Product

Comparing the cost of Nitralloy material with carburizing steels disclosed the following figures: Nitralloy, 0.14 cents per pound; S.A.E. 1020, 0.07 per pound; and S.A.E. 3115 and 2315, 0.10 per pound.

On a 60-hour run the electrical energy consumed was 237 kw-hr. at a cost of $3.08, and the ammonia consumed was 1080 cu. ft. at a cost of $8.21.

These figures are for a small Homo furnace of 300 lb. or $1^1/_2$ cu. ft. capacity. Of course the cost of the ammonia and electrical energy per 100 lb. capacity decreases rapidly as the furnace size increases, so that the cost of nitriding in large quantities should compare quite favorably with carburizing when done in equal quantities.

An element of the cost of a nitrided product is the re-machining after heat treatments which required a second set-up. To prevent the nitriding action on a part of any given surface, several methods may be used. European practice covers that portion not to be hardened with a heavy nickel plate. Tinning the portion not to be hardened or covering with ordinary solder is an effective preventative through care must be used to see that all excess tinning material is removed or prevented from dropping onto other parts of the work as the material becomes molten during nitriding. A newer and more easily applicable preventative not subject to the foregoing difficulty is the painting of those portions not to be hardened with a coating of oxide of tin in glycerin.

A questionnaire circulated to the Diesel-engine industry asked the following questions:

1 Have you made use of nitride-hardening steels in any of the parts of your product?
2 What were the anticipated advantages which led you to turn to the nitride-hardening steels?
3 Have the anticipated advantages materialized? As a frank, unbiased discussion confined entirely to users is contemplated, reports of unsuccessful as well as successful applications will be appreciated.
4 Are there additional parts of your product in which the use of nitride-hardening steels seems attractive?
5 What are the reasons which have deterred you from the use of this material for the parts just named?

1 Of the replies received, seven of the Diesel-engine manufacturers indicated the application of nitrided Nitralloy to the following parts, quite a few being in the experimental stage: Fuel-valve tappets and guides, fuel-pump plungers and cylinders, fuel-pump regulator, bypass valves and guides, valve stems, valves and seats, piston wristpins, piston rods, gears, fuel-injection nozzles, crankshafts, cylinder liners, fuel-nozzle spray tips, fuel-nozzle check valves, and cams.

2 and 3 In nearly every instance the anticipated advantages were as follows: (*a*) Closer fits without danger of sticking and seizing, (*b*) elimination of distortion in heat treatment, (*c*) resistance to corrosion, (*d*) increased wear due to extreme hardness of case, and (*e*) ease with which the parts are handled in the shop due to the material being finished to size before nitriding.

4 Of seven replies received four mentioned various parts they had contemplated making of nitrided Nitralloy, among which were the following: Cylinder liners for high-speed Diesel engines, pins, valve guides, push-rod ends, rollers, valves and seats, plungers and bushings, and buttons for exhaust tappets.

5 In most cases manufacturers had been deterred from the use of nitrided materials due to lack of equipment for handling such work, the extra cost of material, nitriding, and machining, and in some cases it was felt that the additional cost was not justified as compared with the service obtained from these parts as now made.

One Diesel-engine manufacturer reported a rather unusual application of nitrided Nitralloy. The piston rod for one engine was the largest ever nitrided, 14 ft. long, $6^1/_4$ in. in diameter, and weighing approximately 1400 lb. After nitriding, it was found that the rod had warped only 0.020 in. in its entire length.

The outstanding use of Nitralloy in the Diesel-engine field will probably be its application to the details of the fuel-injection system, particularly to fuel-pump plungers and bushings, bypass valve stems and guides, distributor disks, and in fact any place where extreme precision is required and danger of scoring is invited by close operating clearances with absence of good lubrication facilities. Neither on test nor in service have examples of sticking or scoring been known to the author, though in test instances, parts have been fitted to less clearance than would be required for the purpose of causing scoring if possible, but without objectionable results.

Discussion

P. R. Letz.[2] It is gratifying that this paper outlines completely the present uses of nitrided Nitralloy and gives some possibilities of applications on the various parts of engines, but it is difficult to agree with several statements made in this paper.

While it is claimed that a nitrided Nitralloy possesses rustless properties to a decided degree its resistance to corrosion cannot be compared with stainless steels. Even the rustless properties are decreased very materially when the outer soft film, which is formed during the process of nitriding, is removed. In a series of tests carried out under the writer's supervision to determine the resistance to corrosion of various metals to hydrogen-sulphide gas, it was found that nitrided Nitralloy resists under the conditions of the test only slightly better than cast iron containing 12 per cent steel and not nearly as well as stainless steel. The losses of weight per square meter of area at the end of the 400-hr. test were: cast iron, 248 grams; nitrided nitralloy, 192.2 grams; and stainless steel, 24.8 grams.

Fatigue resisting properties of nitrided Nitralloy are illustrated in this paper by describing a test carried out by an automobile manufacturer. This test checks up closely with the tests conducted in the laboratories of the Cooper-Bessemer Corporation on the cantilever type fatigue-testing machine. Nitralloy G, $1^3/_8$ in. round, was used for the test. A series of fatigue and tensile test bars were made from this steel and tested before they were

[2] Chief Inspector, The Cooper-Bessemer Corp., Mt. Vernon, Ohio, and Grove City, Pa.

nitrided and after nitriding. Average results of tensile tests were as follows:

HEAT-TREATED TEST BARS BEFORE NITRIDING

Yield point	Tensile strength	Elong. in 2 in.	Red. of area
74,550	102,500	25.3	63.2

TENSILE TESTS FROM THE SAME STEEL AFTER NITRIDING

83,350	107,000	10.2	12.3

Fatigue Test. Under 75,000 lb. per sq. in. stress the heat-treated Nitralloy broke on the fatigue testing machine at 40,800 reversals. When the same stress was put on the nitrided test bar it did not break after 28,000,000 reversals. Only when 85,000 lb. per sq. in. stress was applied, the nitrided specimen broke at 1,000,411 reversals.

The explanation which is given in the paper for the increase in fatigue-resisting properties of nitrided Nitalloy is as follows:

"The reason for marked difference in results is that the long period during which the material is held at approximately 1000 deg. fahr. during the nitriding operation has a normalizing effect upon the core thoroughly relieving any internal stresses which would tend to start fatigue failures in service."

Not denying the importance of relieving the internal stresses by prolonged heat treatment, the writer cannot agree that this is the main reason for increasing fatigue-resisting properties of nitrided Nitralloy. It seems that a tremendous increase of strength in the nitrided case prevents the fatigue check from starting. The effect of stress concentration on the surface in the Nitralloy case is minimized due to the exceedingly dense structure of the case and freedom of defects, such as soft spots, etc.

A good many parts of the engine have been tried out of the nitrided Nitralloy by The Cooper-Bessemer Corp. In a few cases the cost was found to be prohibitive for adopting this material and in other cases several failures prevent the change from being made. These failures could be briefly summarized to two faults of nitrided Nitralloy: (1) Brittleness of the edges, and (2) soft core not capable of supporting a comparatively thin nitrided case under concentrated loads.

The new developments of the process make it possible to increase the toughness and prevent to a certain degree the chipping off of the edges on the nitrided case. However, very few things have been done in increasing the hardness of the core. As soon as this problem is worked out satisfactorily, nitrided parts could be used for such applications as roller and ball bearings, where the loads are concentrated to a great degree.

J. Barraja-Frauenfelder.[3] One of the slides shown was a piston rod of the Cooper-Bessemer Company. The writer is quite sure that the rod shown is one belonging to a two-cycle double-acting engine built experimentally for a company with which the writer is connected. This rod is approximately 4 ft. long and $5^3/_8$ in. in diameter; it is nitrided throughout and has been in operation about 1250 hr. at present.

In a double-acting engine four qualities in a piston rod are desired: resistance against the stuffing-box packing wear, against corrosion in the bore due to the circulating water, against heat in the combustion space, and against fatigue due to the rapidly alternating stresses. All of these four qualities are obtained with nitriding. The suggestion to use Nitralloy nitrided was accepted with some fear. The test results were fully up to expectations. The rod has now undergone over 28 million reversals of stresses without distress and it is planned to reach 40 millions before it is considered an unqualified success. The writer does not wish to imply that the Cooper-Bessemer Co. did not use a nitrided rod, but only to convey that the particular one shown on the slide was the writer's.

N. F. Hench.[4] If the surface of two nitrided parts working together become damaged, such as scoring from excessive friction, lack of lubrication, or from foreign matter working in between the finished parts, requiring re-surfacing by grinding or lapping in parts together, how deep into the surface can grinding or lapping be carried on without losing the value of the nitrided surface?

P. H. Schweitzer.[5] The nitriding process may revolutionize Diesel-engine design. The Diesel engine ten years from now will not only perform better and last longer, but will look different from the present-day engine. The new materials will suggest a change in the arrangement and shape of the constructional parts, and the design will gradually adjust itself to the new materials. The result will be better engines for less money. Think what one material, rubber, did to the automobile. When it was first introduced no one could have dreamed of the far-reaching consequences.

Nitrided steel may have a similarly far-reaching effect on machine design. It is entertaining to speculate on the near-by consequences of the nitriding process on Diesel-engine design, although the chances are that many of the guesses will prove to be wrong.

Practically all wear in machinery is caused by rubbing. Therefore, wherever possible, rubbing friction in machinery is avoided. Frequently one goes a long way to avoid rubbing friction. When it cannot be avoided lubricants are used to reduce the rubbing friction. Many hundred million dollars are spent in the United States yearly to reduce friction between machine parts. This is done partly to save energy, i.e., fuel necessary to overcome frictional resistance, but more so to reduce wear.

If the latter should become a minor consideration, the present economical equilibrium might be upset. The wear due to friction being negligible it might be economical to permit metallic surfaces to be negligible; it might be proper to simplify design and omit efforts to eliminate rubbing contact at the expense of a more complicated and more expensive construction.

For example, for cam followers the roller is standard except in inexpensive automobiles. Tappets or fixed shoes on rockers are simpler, lighter, and less expensive, but they wear quicker. The writer predicts that due to the nitrided steel the roller followers will entirely disappear, even on large Diesel engines, and nitrided shoes or tappets will take their place.

One of the most annoying things in large Diesel engines is cylinder wear, in small Diesels the erosion of the small nozzle orifices, and in both small and large sizes the wear of pump plungers. For nozzle orifices, for nozzle and fuel-pump plungers and sleeves the use of nitrided steel will become universal. With that material closer fits can be used and they will keep.

The use of nitrided-steel liners and eventually piston rings will make frequent dismantling of cylinders for maintenance superfluous. Then the accessibility of the parts will be a less important consideration. There may result a comeback of the integral heads.

Inserted nitrided-steel sleeves for valve guides will eventually be welded in place for better heat transmission. The use of soft bearing metals will decrease with the increased use of nitrided material for shafts. An unlined aluminum connecting rod on a nitrided crackshaft is an interesting possibility.

[3] Consulting Engineer, Philadelphia, Pa.

[4] Asst. Supt. Marine Dept., Atlantic Refining Co., Philadelphia, Pa. Mem. A.S.M.E.

[5] Associate Professor Engineering Research, Pennsylvania State College, State College, Pa. Mem. A.S.M.E.

Nitrided steel may open up an entirely new road for development, that is, the use of higher compression ratios. The use of higher compression ratios like 18 or 20 instead of the conventional 14 or 15 has distinct possibilities, particularly for high-speed engines. The higher pressure and temperature are bound to reduce the ignition lag, which is a serious obstacle in speeding up the Diesel engine. The extra high compression ratios are, however, very hard on piston rings and liners. Progress in making these parts of nitrided steel may pave the way for the extra-high compression ratios.

L. F. Burger.[6] In using Nitralloy steel for cylinder liners some difficulty arises when the upper end of the liner is threaded in the holes for the spray nozzle. The work must be practically all done on these cylinder liners before the liner is nitrided. During this operation the threads must be protected in order to make them strong enough when put into use and at the same time have a good fit. In doing so, the question came up, what would be the best plan to protect these threads? A cast-iron ring was proposed. As the cast iron would stand the heat, this sleeve or ring would be screwed on to the Nitralloy sleeve and then the nitriding operation takes place. It was found that this works out fairly well, but not as good as one would wish, and it may be necessary to go back to the old system of tinning the threads. The writer would like to know what can be done in a condition of this kind.

In regard to the fuel-pump situation, the writer has had some experience with the fuel-pump plunger passing a hole in the barrel. The plunger passed the hole from $^1/_8$ in. to $^5/_{32}$ in. This seems to be fairly satisfactory, but after a while the pump leaks. Most of the leakage is at the point where the plunger passed the hole in the barrel. This wear was due to very poor oil which contained quite a lot of grit and erosive matter. Considerable erosive matter was removed in various places in the pump.

One would not expect that the pump would give long service with such poor oil. It is felt that there is going to be a great future for this material. In a short time all the new engines will be using Nitralloy steel nitride. Even with this high-grade steel, unless the oil companies produce a cleaner oil, the engine builders will still be at a handicap.

On the other hand, an engine operating on gasoline, which has run since early this spring, having an aluminum piston, Nitralloy sleeve, aluminum connecting rod, and a Nitralloy crankshaft, has been running practically all of the time, and up to the present has shown no wear that could be measured.

[6] International Harvester Co., Chicago, Ill.

Regarding engine sleeves made of Nitralloy steel, the writer cannot agree that this steel can be nitrided without changing its shape. For instance, with a $4^1/_2$-in. sleeve which had a true dimension of $4^1/_2$ in. before nitriding, it was necessary to regrind to 0.008 in. oversize, in order to have the sleeve round, and in doing so the hardness was reduced to 90 Shore.

C. H. Taylor.[7] What is the possibility or the practicability of using Nitralloy as two rubbing surfaces, the fully hardened surfaces working against each other? Is there any difference in the hardness required for the two surfaces? Can the highest hardness be used one against the other for relatively moving parts?

E. T. Larkin.[8] Replying to the ability of the nitrided surface to resist impact forces, and the strength as regards spalling or other surface failures, is there any tendency toward flaking?

C. Harold Berry.[9] Speaking not as a metallurgist but as one who has seen nitrided valve parts enter the steam-power field, the writer reports that nitriding seems to be the complete solution of valve difficulties due to scoring and tearing of seating surfaces. Two nitrided pieces that were rubbed together dry in a testing machine under a load of 200 lb. per sq. in. with a movement of 1 in. at the rate of 120 times per minute completed 100,000 back-and-forth movements with no sign whatever of the least effect on the surface. In plant service, large gate valves with nitrided disk and seat rings seem to give promise of standing up indefinitely.

The steam accumulator often proves effective in balancing variable steam supply and demand. The circumstances that are favorable to an accumulator are low pressure level, large pressure variation, and moderate quantity of steam to and from the accumulator. Whether the steam quantity is at a low rate for a long time or at a high rate for a short time is immaterial, for the size of the accumulator is determined by the total quantity of steam produced or absorbed, and the pressures at the beginning and end of the period. For high pressures, for small pressure variations, or for large steam quantities, the accumulator often proves too large and costly to be justified, but for more moderate requirements in one or more respects, its possibilities should not be overlooked. In operation it is wholly automatic and its maintenance should be negligible.

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OGP-52-10

Economics of the Use of Diesel Engines for Electric Power Generation

By T. A. BURDICK,[1] FORT WORTH, TEXAS

A discussion of the application, merits, and economics of Diesel-engine generating plants for the production of electric energy for distribution and sale, together with unit, investment, and operating cost figures, and a complete tabulation of the results obtained in three different practical solutions of a specific problem.

IN CONSIDERING use of Diesel-electric generating units in the production of electric power for distribution and sale, the economic side of the situation is of probably the greatest concern to interested individuals. With this thought in mind, the author has assembled and is presenting tabulated figures of investment and operating costs which are representative of his experience to date. The figures presented therefore should be accepted merely on the basis of one man's experience in the southwestern section of the United States. It is felt, however, that with slight modification for variations in conditions which may be encountered in other localities, these figures may be accepted in the study of the production and distribution of electric energy in any section of the country. Unit figures will be subject to some little variation under different conditions peculiar to the specific location.

In presenting a solution for a typical problem which may be met in the electric-utility industry, the purpose is to present a method of attack in the consideration of such a problem rather than to indicate a correct solution. The great number of variable quantities and values involved makes possible many different solutions, some one of which will likely be the best in the specific case, but others of which may have considerable merit.

In certain fundamental respects the assumptions of the problem are incomplete, such as, for instance, an assumption in regard to the rate of increase of business of the town served. These facts have not been overlooked, but have merely been disregarded in order to relieve the problem of unnecessary complications.

Investment Costs

The cost of Diesel-electric plants of similar capacity will vary between rather wide limits with variation in local conditions affecting the design and other conditions affecting construction. It will also vary to a consiberable extent with the type of structure selected for the plant, and in case provision is made for installation of additional equipment at some later date, the cost may be increased quite materially. In Table 1 will be found estimated costs of 17 different Diesel-electric generating plants of representative design and varying in installed capacity from 117 kw. to 10,110 kw. The cost of the plant has been subdivided into five different accounts which were selected from the N.E.L.A. classification. Certain assumptions have to be made in the selection of equipment for the plants and in the selection of the type of structure. The designs on which these estimates are based and the cost of the installations are consistent with actual experience in the construction of many similar plants.

Plants one to six inclusive are equipped with two-cycle airless-injection engines; other plants have two-cycle and four-cycle air-injection engines. Plants one to five inclusive are

TABLE 1 REPRESENTATIVE COSTS OF DIESEL-ELECTRIC GENERATING PLANTS

Plant No.	Generating units: No.	Capacity: Hp.	Capacity: Kw. each	Capacity: Total kw.	Cost, dollars: Land	Structures	Engines	Elec. plant	Aux. and access.	Total	Cost per kw. gen. capy.
1	1	60	39	...	.....	.....	.....	.....	.....	.....	.....
	1	120	78	117	1,000	3,758	14,920	8,659	4,777	33,114	283
2	2	120	78	156	1,000	3,758	19,388	9,583	5,457	39,186	251
3	2	180	117	234	1,000	6,713	27,990	10,531	7,304	53,538	229
4	2	240	157	314	2,000	7,220	35,246	13,878	10,753	69,097	220
5	3	180	117	351	2,000	11,828	41,989	16,162	11,971	83,950	239
6	3	240	157	471	2,000	12,522	52,876	19,092	16,801	103,291	219
7	2	400	266	532	2,000	12,781	64,629	17,626	16,328	113,364	213
8	3	400	266	798	4,000	14,662	96,937	24,884	21,374	161,857	203
9	3	500	336	1008	4,000	30,678	118,927	28,215	25,468	207,288	206
10	3	600	405	1215	4,000	30,678	134,681	29,047	29,185	227,591	187
11	3	800	547	1641	4,000	36,215	175,592	33,210	35,212	284,229	173
12	2	1200	832								
	1	800	547	2211	4,000	42,717	217,678	34,745	44,885	344,025	156
13	3	1200	832	2496	4,000	42,717	239,589	38,616	46,092	370,994	149
14	3	1800	1248	3744	8,000	45,002	360,969	55,470	55,579	525,020	140
15	2	1800	1248								
	2	2400	1685	5866	8,000	55,990	553,240	75,507	75,181	767,918	131
16	5	2400	1685	8425	8,000	62,005	781,760	96,160	93,991	1,041,916	124
17	6	2400	1685	10110	8,000	68,668	938,023	113,492	108,213	1,236,396	122

Notes:
1 Fifteen per cent overhead cost has been included in all figures.
2 Plants 1 to 6 inclusive are equipped with two-cycle airless-injection engines; others with two-cycle and four-cycle air-injection engines.
3 Plants 1 to 5 inclusive are equipped with an open-type jacket water-cooling system; others with a closed-type system and heat exchangers.
4 Plant structures 1 to 4 inclusive are wood frame covered with corrugated metal; structures 5 to 8 inclusive are steel frame with corrugated asbestos cover; structures 9 to 17 inclusive are steel frame, brick wall, and fire-resisting roof construction.
5 Power plant equipment has been separated into three accounts, each of which bears its proper proportion of installation, foundation, and overhead costs.

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Presented at the Third National Oil and Gas Power Meeting, State College, Pa., June 12 to 14, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

TABLE 2 REPRESENTATIVE COSTS OF SINGLE-CIRCUIT WOOD-POLE TRANSMISSION LINES

Line voltage	No. phases	Type of construction	Conductor A.C.S.R.	Standard spans, ft.	Standard poles Height, ft.	Standard poles Top, in.	Cost per mile in dollars: Overhead conductors	Poles, towers, etc.	Land	Total
6600 volts	1	Pin type single pole	No. 4	278	35	7	275	593	258	1,126
6600 volts	1	Pin type single pole	No. 2	330	35	8	413	560	217	1,190
6600 volts	3	Pin type single pole	No. 4	278	35	7	407	605	258	1,270
6600 volts	3	Pin type single pole	No. 2	330	35	8	615	570	217	1,402
11 kv.	1	Pin type single pole	No. 4	278	35	7	321	582	258	1,161
11 kv.	1	Pin type single pole	No. 2	330	35	8	459	560	217	1,236
11 kv.	3	Pin type single pole	No. 4	278	35	7	488	624	258	1,370
11 kv.	3	Pin type single pole	No. 2	330	35	8	684	582	217	1,483
11 kv.	3	Pin type single pole	No. 1/0	440	35	9	990	534	194	1,718
22 kv.	3	Pin type single pole	No. 2	330	35	8	770	617	217	1,604
22 kv.	3	Pin type single pole	No. 1/0	440	35	9	1067	560	194	1,821
33 kv.	3	Pin type single pole	No. 2	330	35	8	833	617	217	1,667
33 kv.	3	Pin type single pole	No. 1/0	440	35	9	1125	560	194	1,879
44 kv.	3	Pin type single pole	No. 2	330	35	8	965	633	217	1,815
44 kv.	3	Pin type single pole	No. 1/0	440	35	9	1230	576	194	2,000
44 kv.	3	Pin type single pole	No. 3/0	480	35	9	1733	526	188	2,447
44 kv.	3	Pin type single pole	No. 4/0	480	35	10	2105	583	188	2,876
66 kv.	3	Susp. "H" frame	No. 1/0	550	45	8	1458	995	343	2,796
66 kv.	3	Susp. "H" frame	No. 3/0	660	45	9	1974	1048	297	3,319
132 kv.	3	Susp. "H" frame	No. 1/0	550	45	8	1903	1054	343	3,300
132 kv.	3	Susp. "H" frame	No. 3/0	660	45	9	2366	1100	297	3,763

GENERAL NOTES

Poles are creosoted yellow pine and 80 per cent of them are figured as being the standard height indicated in the tabulation; 12 per cent are 5 ft. longer; 6 per cent are 10 ft. longer; and 2 per cent are 15 ft. longer.

Labor, material, construction equipment costs, general construction costs, and 15 per cent overheads are distributed in correct proportion to the various divisions of the cost tabulated.

Cost of survey, right of way easements, cost of securing right of way, crop and property damage have been included in "Land."

Aluminum conductor is provided with armor rods and clamps for each point of contact.

TABLE 3 REPRESENTATIVE COSTS OF OUTDOOR-TYPE WOOD STRUCTURE TRANSFORMER STATIONS

Voltage	Transformers No.	Transformers Size, kva.	Type of structure	Switching equipment High voltage	Switching equipment Low voltage	Cost in dollars
2300/6900	1	25	Single pole	Fused disconnect	....	369
2300/6900	2	25	2 pole platform	Fused disconnect	....	827
2300/6900	3	25	2 pole platform	Fused disconnect	....	1,121
2300/6900	1	37.5	Single pole	Fused disconnect	....	435
2300/6900	2	37.5	2 pole platform	Fused disconnect	....	994
2300/6900	2	50	2 pole platform	Fused disconnect	....	1,144
2300/6900	3	50	2 pole platform	Fused disconnect	....	1,582
2300/6900	2	75	2 pole platform	Fused disconnect	....	1,344
2300/11000	1	25	Single pole	Fused disconnect	....	451
2300/11000	3	25	2 pole platform	Fused disconnect	....	1,815
2300/11000	1	37.5	Single pole	Fused disconnect	....	536
2300/11000	3	37.5	2 pole platform	Fused disconnect	....	1,990
2300/11000	2	50	2 pole platform	Fused disconnect	....	1,920
2300/11000	3	50	2 pole platform	Fused disconnect	....	2,340
2300/11000	3	75	2 pole platform	Fused disconnect	....	2,572
2300/11000	3	100	2 pole platform	Fused disconnect	....	3,090
2300/11000	3	150	2 pole ground	Fused disconnect	....	3,294
2300/11000	2	200	2 pole ground	Fused disconnect	....	3,067
2300/22000	3	25	2 pole platform	Fused disconnect	....	2,507
2300/22000	3	50	2 pole platform	Fused disconnect	....	3,025
2300/22000	3	75	2 pole platform	Fused disconnect	....	3,385
2300/22000	2	100	4 pole platform	Fused disconnect	....	3,141
2300/22000	3	100	4 pole platform	Fused disconnect	....	4,006
2300/22000	3	150	4 pole ground	Fused disconnect	O.C.B.	6,744
2300/22000	2	200	4 pole ground	Fused disconnect	O.C.B.	6,139
2300/22000	3	200	4 pole ground	Fused disconnect	O.C.B.	7,227
2300/11000/22000	2	100	4 pole platform	Fused disconnect	....	3,144
2300/11000/22000	2	200	4 pole ground	Fused disconnect	....	7,405
6900/22000	3	50	2 pole platform	Fused disconnect	....	3,025
6900/22000	3	75	2 pole platform	Fused disconnect	....	3,405
2300/33000	3	50	4 pole platform	Fused disconnect	O.C.B.	3,573
2300/33000	3	100	4 pole platform	Fused disconnect	O.C.B.	4,508
2300/33000	3	200	4 pole ground	Fused disconnect	O.C.B.	8,564
2300/33000	3	333	4 pole ground	Fused disconnect	O.C.B.	9,948
2300/44000	1	25	4 pole ground	Fused disconnect	....	3,091
2300/44000	3	25	4 pole ground	Fused disconnect	....	4,177
2300/44000	1	37.5	4 pole ground	Fused disconnect	....	3,211
2300/44000	3	37.5	4 pole ground	Fused disconnect	....	4,477
2300/44000	2	50	4 pole ground	Fused disconnect	....	4,488
2300/44000	3	50	4 pole ground	Fused disconnect	....	5,228
2300/44000	2	100	4 pole ground	Fused disconnect	O.C.B.	5,428
2300/44000	3	100	4 pole ground	Fused disconnect	O.C.B.	6,434
2300/44000	3	150	4 pole ground	Fused disconnect	O.C.B.	6,980
2300/44000	3	200	4 pole ground	Fused disconnect	O.C.B.	10,100
2300/44000	3	333	4 pole ground	Fused disconnect	O.C.B.	11,656
2300/44000	3	400	4 pole ground	Fused disconnect	O.C.B.	12,606
2300/44000	3	500	4 pole ground	Fused disconnect	O.C.B.	13,490
2300/44000	3	2500	4 pole ground	Fused disconnect	O.C.B.	29,585
2300/66000	3	500	6 pole ground	O.C.B.	O.C.B.	21,810
2300/66000	3	1000	6 pole ground	O.C.B.	O.C.B.	30,670
2300/66000	3	2000	6 pole ground	O.C.B.	O.C.B.	41,345

NOTE: No line sectionalizing switches included.

equipped with open-type jacket water-cooling systems, and others with closed-type systems and heat exchangers. Plants one to four inclusive are housed in wood-frame structures covered with corrugated metal; five to eight inclusive are housed in steel-frame structures with corrugated asbestos covering; nine to seventeen inclusive are housed in steel-frame structures with brick walls, fire-resisting roof construction, and modest exterior decorations. In general the structures have been made large enough to accommodate one additional generating unit. All of the engines have sea-level ratings; however, loss of power due to the increase in elevation will not be sufficient to affect the figures to any extent below 3500 ft. elevation.

Fifteen per cent overhead costs have been included in all figures, overhead being understood to cover administrative expense, cost of financing, engineering, superintendence, cost of purchasing and storing material, construction accounting, interest, and insurance during construction. Detailed estimates have been prepared on all of the plants listed, but it has not been found practicable to include the details in this paper. Cost of the various items of equipment is based on recent quotations, and the point of delivery selected is Texas.

In studying the cost of producing and distributing electric current, it becomes necessary to know the cost of transmission lines, transformer substations, and distribution systems. In Tables 2, 3, and 4 will be found outline data and estimated average costs of each of the above items. The cost figures submitted are based on finished designs and actual construction, and are representative of good practice in the southwest. Sufficient ground has been covered in these cost tabulations for selection of all facilities required in the solution of a problem to be discussed later.

OPERATING COSTS

The next item of interest after studying investment costs are costs of operation. In Table 5 there are presented representative operating and maintenance cost figures and unit economy figures for each of the Diesel-electric plants listed in Table 1. The figures presented are based on average good results obtained in the use of such plants in electric utility operation. No attempt has been made in this tabulation to show results other than those that can and have actually been obtained, and which under normal circumstances are representative of the various types of plants

listed. Fuel oil is of 18,500 B.t.u. heat content, and of gravity and viscosity best suited to the type of engine in which it is burned. Figures appearing in this tabulation will be used later in the solution of a problem to be discussed.

Under operating costs the matter of fixed charges on investment must be considered. For use in this paper a figure of 13½ per cent has been selected consisting of 6 per cent interest, 6 per cent depreciation, and 1½ per cent for insurance and taxes. This figure is applied to the total investment both in plant and distribution facilities and may therefore be considered an average figure.

In Tables 6 and 7 will be found representative costs of operation and maintenance of wood-pole transmission lines and electric distribution systems respectively. It is quite conceivable that there may be a wide difference of opinion as to whether these figures are sufficiently accurate to be called representative. There is found to be a very wide variation in cost, depending on many variable factors such as the extent of the system, climatic conditions, and price of labor. The figures presented in this tabulation have been selected, however, as representative of the average costs to be realized in a system of some magnitude and located in the southwestern section of the country.

TABLE 4 REPRESENTATIVE COST OF ELECTRIC DISTRIBUTION SYSTEMS

Number connections per town	Voltage	Cost per connection, dollars	Cost per town, dollars
100	2,300	108	10,800
150	2,300	89	13,350
200	2,300	81	16,200
250	2,300	76	19,000
500	2,300	66	33,000
1000	2,300	60	60,000
100	6,600	112	11,200
150	6,600	94	14,100
200	6,600	86	17,200
250	6,600	81	20,250
500	6,600	71	35,500
1000	6,600	65	65,000

TABLE 5 REPRESENTATIVE OPERATING AND MAINTENANCE COSTS AND ECONOMIES OF DIESEL-ELECTRIC POWER PLANTS

Plant No.	Generating units: No.	Generating units: Hp.	Total plant capacity: Hp.	Total plant capacity: Kw.	Auxiliary power: Kw-hr. per hp. per yr.	Auxiliary power: Kw-hr. per year	Fuel economy, kw-hr. gen. per gal. fuel	Lubr. oil economy, kw-hr. gen. per gal. lubr. oil used	Plant: No. employees	Plant: Rate per month	Labor Total cost per year	Misc. supplies Dollars per year	Repairs to Diesel engines: Dollars per hp. per yr.	Repairs to Diesel engines: Total per year	Maint. of bldgs. and grounds Dollars per year	Maint. of electric equip. Dollars per year	Maint. of pr. plant aux. equip. Dollars per year
1	1 1	60 120	180	117	120	21,600	6	215	1 1	135 100	2,820	200	3.40	612	36	87	72
2	2	120	240	156	120	28,800	7	267	1 1	135 100	2,820	240	3.15	757	36	96	82
3	2	180	360	234	120	43,200	8	570	1 2	135 100	4,020	330	2.75	990	58	105	110
4	2	240	480	314	120	57,600	8.5	740	1 2	150 100	4,200	410	2.25	1,080	69	139	161
5	3	180	540	351	120	64,800	8.5	880	1 2	150 115	4,560	445	2.05	1,105	104	162	180
6	3	240	720	471	120	86,400	9	1,120	1 2	150 125	4,800	540	1.60	1,150	109	191	252
7	2	400	800	532	120	96,000	11	1,220	1 2	160 125	4,920	560	1.50	1,200	111	176	245
8	3	400	1,200	798	120	144,000	11	1,440	1 2	175 125	5,100	710	1.24	1,488	140	249	321
9	3	500	1,500	1,008	119	178,500	11	1,490	1 3	175 125	6,600	810	1.15	1,725	260	282	382
10	3	600	1,800	1,215	119	214,200	11	1,510	1 3	200 135	7,260	920	1.14	2,055	260	290	438
11	3	800	2,400	1,641	115	276,000	11	1,530	1 3	200 150	7,800	1,080	1.12	2,688	302	332	528
12	1 2	800 1,200	3,200	2,211	110	352,000	11	1,550	1 3	225 150	8,100	1,200	1.11	3,552	350	347	673
13	3	1,200	3,600	2,496	108	388,800	11	1,570	1 1 2 1	225 175 150 100	9,600	1,260	1.11	3,996	350	386	691
14	3	1,800	5,400	3,744	102	550,800	11	1,610	1 1 2 1	250 175 150 100	9,900	1,430	1.10	5,040	398	555	834
15	2 2	1,800 2,400	8,400	5,866	100	840,000	11	1,680	1 1 3	275 175 150	10,800	1,890	1.10	9,240	480	755	1,128
16	5	2,400	12,000	8,424	98	1,176,000	11	1,700	1 2 3	300 175 150	13,200	2,640	1.10	13,200	525	962	1,410
17	6	2,400	14,400	10,110	96	1,382,400	11	1,700	1 2 3	300 175 150	13,200	3,020	1.10	15,840	575	1,135	1,623

TABLE 6 REPRESENTATIVE COST OF OPERATION AND MAINTENANCE OF WOOD-POLE TRANSMISSION LINES

Dollars per year per mile of line with voltage as indicated					
6600	11000	22000	33000	44000	66000
15	16	18	20	21	23

TABLE 7 REPRESENTATIVE COST OF OPERATION AND MAINTENANCE OF ELECTRIC DISTRIBUTION SYSTEMS

Dollars per year in towns with number of connections as shown					
100	150	200	250	500	1000
360	540	720	900	1600	2400

TABLE 8 CLASSIFICATION OF CUSTOMERS IN TOWNS OF VARIOUS SIZES

Classification	Per cent of total customers in each classification in towns with number of connections as shown: 100	150	200	250	500	1000
Residential	60	60	60	60	59	57
Commercial light	25	23	22	21	19	17.5
Residential combination	10	10	10	10	11	13
Heating and refrigeration	2	2	2	2	2	3
Small power	3	3.5	4	4.5	5.5	6
Large power	...	...	...	0.1	0.4	0.6
Miscellaneous	...	1.5	2	2.4	3.1	2.9
Total	100	100	100	100	100	100

Load Data

In studying the application of Diesel-electric plants to electric utility systems, it is necessary to have some knowledge of the characteristics of the loads to be served. In this paper consideration is being given to electric service in small and moderate-sized towns. The towns to be considered will run in population from

TABLE 9 YEARLY DEMAND AND CONSUMPTION IN TOWNS OF VARIOUS SIZES

	Demand in kw. and consumption in kw-hr. per year in towns with number of connections as shown											
	100		150		200		250		500		1000	
Classification	Demand	Consumption	Demand	Consumption	Demand	Consumption	Demand	Consumption	Demand	Consumption	Demand	Consumption
Residential	3.88	6,120	6.50	10,250	9.15	14,400	12.00	18,900	25.9	40,750	52.2	82,200
Commercial light	4.43	7,750	8.66	15,200	13.30	23,300	18.30	32,000	48.8	85,500	113.0	198,000
Residential combination	13.20	17,400	20.50	26,900	28.00	36,900	35.80	47,100	82.5	108,500	201.0	264,000
Heating and refrigeration	1.10	2,400	2.35	5,150	4.00	8,750	5.55	12,180	13.6	29,750	45.6	99,700
Small power	1.22	3,530	2.22	6,420	3.52	10,175	5.13	14,850	14.8	42,800	37.6	108,700
Large power	...	...	...	...	...	...	5.00	16,500	57.0	300,000	377	1,980,000
Miscellaneous	...	...	2.47	5,400	4.93	10,800	8.20	18,000	27.6	60,350	64	139,300
Total	27.83	37,200	42.63	69,320	62.90	104,325	89.98	159,530	270.2	667,650	890.4	2,871,900
Per cent loss in distr. system		16		15		14		13.5		11.5		10
Kw-hr. loss in distr. system		7,100		12,280		16,675		24,470		87,350		318,100
Kw-hr. input to town		44,300		81,600		121,000		184,000		755,000		3,190,000
Diversity factor	1.25		1.25		1.25		1.25		1.25		1.25	
Kw. demand from load	22.3		34		50.3		72		216		712	
Kw. demand from distr. transf. core losses	0.3		0.5		0.7		1		3.5		12.7	
Kw. demand from copper losses	2.4		3.5		5		7.0		26.5		94.3	
Total demand kw.	25		38		56		80		246		819	
Average power factor	92		90		89		88		86		84	
Total demand kva.	27		42		63		91		286		975	
Yearly load factor	15.5		24.5		25		26		35		37.5	
Kva. demand per connection	0.27		0.28		0.315		0.365		0.57		0.975	

500 to 5000 and the number of electric connections will vary correspondingly from 100 to 1000. In Table 8 there is presented a typical classification of electric-system customers, together with a statement of the per cent of the total customers in each class in towns of various sizes. In towns of 100 and 150 connections, load is assumed to be single-phase while in larger towns it is three phase.

In Table 9 are shown representative figures of demand and consumption of all customers in each of the various classes and each of the various sizes of towns. These figures are brought to a total which is to indicate the customer demand and consumption in each of the towns. Representative figures of losses or unaccounted-for energy in distribution systems are also indicated in this tabulation; the losses being added to customer consumption to give a figure of total kw-hr. delivered into the local system. Additions to demand due to the system losses have also been computed and added to the customer demand figure after application of an average diversity factor of 1.25, to give an effective annual kilowatt-demand figure.

In distribution systems such as those considered, it has been found by analysis and calculation that the losses will be divided up about as follows: Transformer core loss 35 per cent, transformer copper loss 25 per cent, line loss 40 per cent. The transformer core-loss energy will have a load factor of 100 per cent and therefore the yearly maximum demand of this loss will be the kw-hr. yearly loss divided by 8760. On the assumption that the maximum load current is on the line 14.3 per cent of the time, $1/2$ of the maximum load current is on the line 28.5 per cent of the time, and $1/4$ of the maximum load current is on the line 57.2 per cent of the time, it is found that 57.2 per cent of the transformer copper and the line losses occurs during the period of maximum loads and therefore the yearly maximum de-

TABLE 10 SELECTION AND COST OF POWER PLANTS FOR EACH OF THREE SOLUTIONS OF PROBLEM PRESENTED, TOGETHER WITH ANNUAL PRODUCTION AND DEMAND

Group number	Sum of town dem., kw.	Combined town dem., kw.	Transm. line loss dem., kw.	Transm. transf. dem. losses Copper, kw.	Transm. transf. dem. losses Core, kw.	Dem. on plant, kw.	Plant aux. dem., kw.	Dem. on gen. units, kw.	Consumption of towns, kw-hr.	Transm. line losses, kw-hr.	Transm. transf. losses Copper, kw-hr.	Transm. transf. losses Core, kw-hr.	Plant production, kw-hr.	Energy used by plant aux., kw-hr.	Total generated, kw-hr.	Plant number	Plant cost, in dollars
Solution "A"—21 local plants																	
A	137	120	1.48	3.17	1.35	126	6	132	286,300	3,102	6,510	11,655	307,567	43,200	350,767	3	53,538
B	296	290	0.68	1.59	0.73	293	12	305	843,600	1,397	3,275	6,140	854,412	86,400	940,812	6	103,291
C	150	130	1.88	3.53	1.59	137	6	143	323,600	3,930	7,340	13,270	348,140	43,200	391,340	3	53,538
D	246	246	0.00	0.00	0.00	246	12	258	755,000	0,000	00,000	00,000	755,000	86,400	841,400	6	103,291
E	963	944	3.11	4.80	2.09	954	40	994	3,481,200	6,836	10,040	18,120	3,516,196	276,000	3,792,196	11	284,229
F	899	889	3.06	2.68	1.26	896	40	936	3,374,000	6,575	5,880	11,040	3,397,495	276,000	3,673,495	11	284,229
G	899	889	3.06	2.68	1.26	896	40	936	3,374,000	6,250	5,880	11,040	3,397,170	276,000	3,673,170	11	284,229
H	327	316	2.89	2.91	1.20	323	20	343	920,300	5,890	5,930	11,575	943,695	144,000	1,087,695	8	161,857
I	237	206	3.73	4.20	2.07	216	9	225	512,500	8,725	9,450	18,325	549,000	64,800	613,800	5	83,950
J	80	80	0.00	0.00	0.00	80	4	84	184,000	0,000	0,000	00,000	184,000	28,800	212,800	2	39,186
K	156	135	1.86	2.10	1.04	140	6	146	347,200	4,280	4,840	9,480	365,800	43,200	409,000	3	53,538
L	993	970	4.07	5.32	2.61	982	40	1022	3,576,600	9,010	11,620	22,890	3,620,120	276,000	2,896,120	11	284,229
M	94	82	0.71	0.90	0.39	84	4	88	202,600	1,780	2,190	4,040	210,610	28,800	239,410	2	39,186
N	94	82	1.30	1.15	0.55	85	4	89	202,600	2,500	2,190	4,040	211,330	28,800	240,130	2	39,186
O	136	118	2.70	2.25	1.05	124	6	130	305,000	5,630	4,920	9,200	324,750	43,200	367,950	3	53,538
P	94	82	1.26	1.20	0.54	85	4	89	202,600	2,330	2,190	4,040	211,160	28,800	239,960	2	39,186
Q	217	190	2.79	4.98	2.23	200	9	209	470,300	5,942	10,650	19,015	505,907	64,800	570,707	5	83,950
R	383	365	2.92	4.91	2.17	375	20	395	1,041,300	6,389	10,650	19,015	1,077,354	144,000	1,221,354	8	161,857
S	56	56	0.00	0.00	0.00	56	3	59	121,000	0,000	00,000	00,000	121,000	21,600	142,600	1	33,114
T	458	430	5.57	6.40	3.03	445	20	465	1,223,200	12,203	14,130	26,560	1,276,093	144,000	1,420,093	8	161,857
U	192	167	5.30	3.85	1.85	178	9	187	426,000	12,060	8,870	16,920	463,850	64,800	528,650	5	83,950
Total	7107	6787	48.37	58.62	27.01	6921	314	7235	22,172,900	104,829	126,555	236,365	22,640,649	2,212,800	24,853,449		2,484,929
Solution "B"—6 local groups and plants																	
1	1237	1183	19	13	6	1221	55	1276	4,102,800	41,275	28,925	52,520	4,225,520	352,000	4,577,520	12	344,025
2	774	706	20	21	10	757	30	787	1,898,200	44,484	45,600	84,590	2,072,874	214,200	2,287,074	10	227,591
3	706	646	18	15	7	686	30	716	1,770,200	39,625	33,690	61,340	1,904,855	214,200	2,119,055	10	227,591
4	1371	1299	21	19	9	1348	55	1403	4,566,800	46,076	40,840	79,720	4,733,436	352,000	5,085,436	12	344,025
5	1582	1482	29	25	12	1548	62	1610	5,053,700	63,810	53,625	108,110	5,279,245	388,800	5,668,045	13	370,994
6	1437	1356	19	21	10	1406	62	1468	4,781,200	42,700	44,820	89,590	4,958,310	388,800	5,347,110	13	370,994
Total	7107	6672	126	114	54	6966	294	7260	22,172,900	277,970	247,500	475,870	23,174,240	1,910,000	25,084,240		1,885,220
Solution "C"—combined system—one plant																	
	7107	6180	287	182	77	6726	252	6978	22,172,900	629,172	398,960	672,450	23,873,482	1,382,400	25,255,882	17	1,236,396

NOTES:

A diversity factor of 1.15 has been applied to the sum of the kw. demands of all towns to determine the combined town demand in solution "C."

The same diversity factor has been applied to the sum of the kw. demands of all outlying towns and the quotient added directly to the kw. demand of the central town of the group to determine the combined town demands in solution "B."

The same principles as above have been applied in solution "A." When the central town is large with respect to the outlying towns, the method used in solution "B" has been followed; and where the towns in a group are of about the same size, the method used in solution "C" has been followed.

mand of these losses will be the kw-hr. yearly loss divided by 2190.

Power-factor conditions in the systems vary to a certain extent, depending on the nature of the load. Representative conditions of power factor are shown in the tabulation, together with total kva.-demand figures for use in transmission calculations. It is interesting to note that, under the assumptions made, the yearly load factors of the towns vary from 15.5 per cent in a town of 100 connections to 37.5 per cent in a town of 1000 connections, and

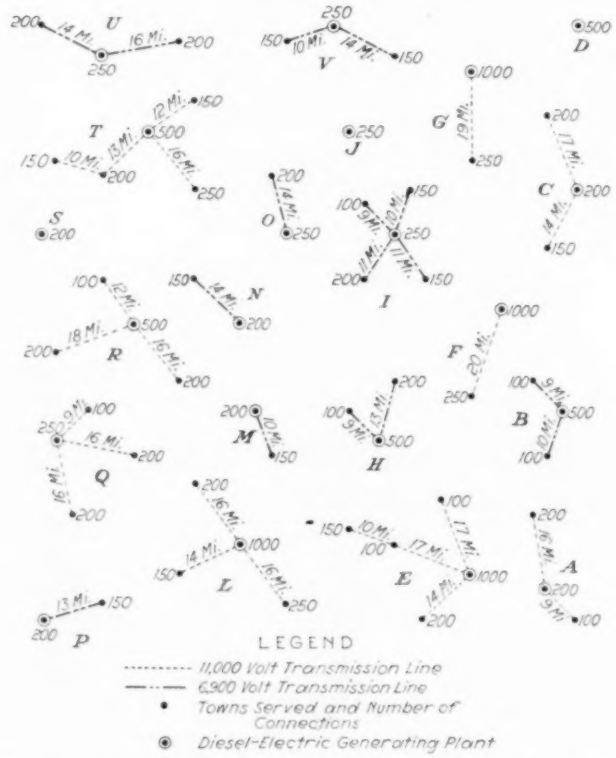


FIG. 1 LOCATION OF PROPERTIES, PLANTS, AND TRANSMISSION LINES FOR PLANTS SERVING ADJACENT TOWNS OVER LOW-VOLTAGE TRANSMISSION LINES
(Transmission conductor No. 4 A.C.S.R.)

TABLE 11 COST OF TRANSMISSION LINES FOR EACH OF THREE SOLUTIONS OF PROBLEM PRESENTED

Line voltage	Phase	Number of miles	Conductor	Unit cost	Cost
			Solution "A"—21 local plants		
6,600	1	119	No. 4 A.C.S.R.	$1,126	$ 133,994
6,600	3	68	No. 4 A.C.S.R.	1,270	86,360
11,000	1	107	No. 4 A.C.S.R.	1,161	124,227
11,000	3	230	No. 4 A.C.S.R.	1,370	315,100
Total					$ 659,681
			Solution "B"—6 local groups and plants		
6,600	1	29	No. 4 A.C.S.R.	$1,126	$ 32,654
6,600	3	11	No. 4 A.C.S.R.	1,270	13,970
11,000	1	47	No. 4 A.C.S.R.	1,161	54,567
11,000	3	334	No. 4 A.C.S.R.	1,370	457,580
11,000	3	152	No. 2 A.C.S.R.	1,483	225,416
22,000	3	215	No. 2 A.C.S.R.	1,604	344,860
Total					$1,129,047
			Solution "C"—combined system—one plant		
6,600	1	10	No. 4 A.C.S.R.	$1,126	$ 11,260
6,600	3	13	No. 4 A.C.S.R.	1,270	16,510
11,000	1	38	No. 4 A.C.S.R.	1,161	44,118
11,000	1	10	No. 2 A.C.S.R.	1,236	12,360
11,000	3	71	No. 4 A.C.S.R.	1,370	97,270
11,000	3	301	No. 2 A.C.S.R.	1,483	446,383
44,000	3	147	No. 2 A.C.S.R.	1,815	266,805
44,000	3	172	No. 1/0 A.C.S.R.	2,000	344,000
44,000	3	197	No. 4/0 A.C.S.R.	2,876	566,572
Total					$1,805,278

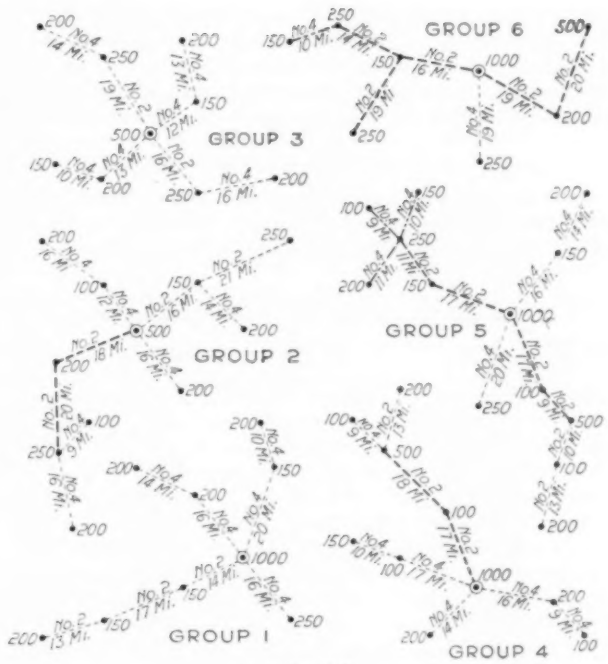


FIG. 2 LOCATION OF PROPERTIES, PLANTS, AND TRANSMISSION LINES FOR LOCAL GROUP ARRANGEMENT WITH SIX PLANTS

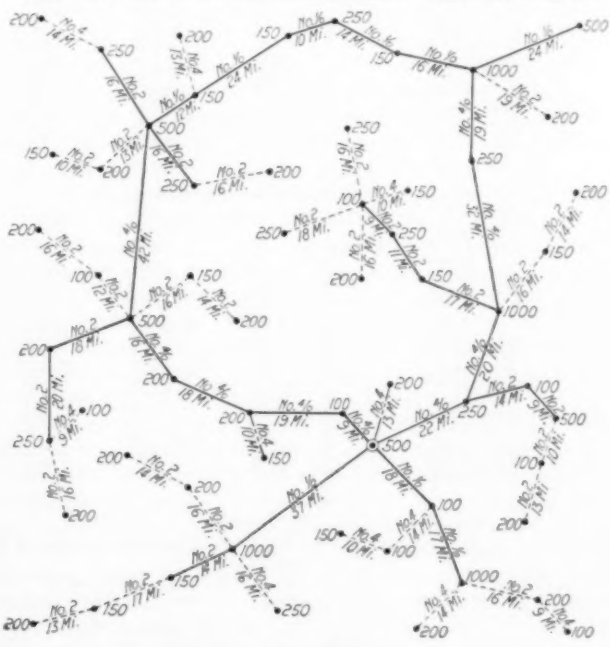


FIG. 3 FOR COMBINED SYSTEM WITH ONE PLANT

similarly the kva.-demand per connection varies from 0.27 kva. to 0.975 kva. These figures on load are presented as fairly representative of conditions to be found in the less thickly populated sections of the country, and will be used as a basis for the load assumptions in the specific problem to be presented.

Illustrative Problem

In order to give a concrete illustration of the probable investment and operating costs of a complete system for the production and distribution of electric energy with energy produced in Diesel plants, a certain problem has been selected and three solutions of the problem are presented herewith for comparison. The problem consists of producing and distributing energy to 15,700 customers in 60 different towns with the number of connections in

TABLE 12 COST OF TRANSMISSION SUBSTATIONS FOR EACH OF THREE SOLUTIONS OF PROBLEM PRESENTED

Number of substations	Voltage	Transformers No.	Transformers Size	Unit cost	Cost
	Solution "A"—21 local plants				
4	2300/6900	1	25	$ 369	$ 1,476
10	2300/6900	1	37½	435	4,350
1	2300/6900	2	25	827	827
6	2300/6900	3	25	1,121	6,726
2	2300/6900	2	50	1,144	2,288
1	2300/6900	3	50	1,582	1,582
1	2300/6900	2	75	1,344	1,344
5	2300/11000	1	25	451	2,255
5	2300/11000	1	37½	536	2,680
9	2300/11000	3	25	1,815	16,355
1	2300/11000	3	37½	1,990	1,990
7	2300/11000	2	50	1,920	13,440
3	2300/11000	3	50	2,340	7,020
1	2300/11000	3	75	2,572	2,572
1	2300/11000	2	100	2,424	2,424
	Total				$ 67,329
	Solution "B"—6 local groups and plants				
6	2300/11000	1	25	$ 451	$ 2,706
8	2300/11000	1	37½	536	4,288
17	2300/11000	3	25	1,815	30,855
7	2300/11000	2	50	1,920	13,440
1	2300/11000	3	75	2,472	2,472
1	2300/11000	2	100	2,349	2,349
1	2300/11000	3	150	3,294	3,294
1	2300/11000	2	200	3,067	3,067
1	2300/11000	3	200	4,067	4,067
2	2300/22000	1	25	1,627	3,254
2	2300/22000	1	37½	1,698	3,396
2	2300/22000	3	25	2,507	5,014
1	2300/22000	2	50	2,440	2,440
1	2300/22000	3	75	3,385	3,385
1	2300/22000	3	100	4,006	4,006
1	2300/22000	3	150	6,744	6,744
2	2300/22000	3	200	7,227	14,454
1	2300/11000/22000	2	100	3,235	3,235
2	2300/11000/22000	2	200	6,758	6,758
1	6900/22000	3	50	3,025	3,025
1	6900/22000	3	75	3,405	3,405
	Total				$125,654
	Solution "C"—combined system—one plant				
1	2300/6900	1	37½	$ 435	$ 435
2	2300/6900	3	25	1,121	2,242
5	2300/11000	1	25	451	2,225
6	2300/11000	1	37½	536	3,216
16	2300/11000	3	25	1,815	29,040
3	2300/11000	2	50	1,920	5,760
2	2300/44000	1	25	3,091	6,182
3	2300/44000	1	37½	3,211	9,633
3	2300/44000	3	25	4,177	12,597
2	2300/44000	3	37½	4,477	8,954
5	2300/44000	2	50	4,488	22,440
3	2300/44000	3	50	5,288	15,864
1	2300/44000	2	100	5,428	5,428
2	2300/44000	3	100	6,434	12,868
3	2300/44000	3	150	6,980	20,940
2	2300/44000	3	333	11,656	23,312
2	2300/44000	3	400	12,606	25,212
1	2300/44000	3	2500	29,585	29,585
	Total				$235,933

TABLE 13 COST INSTALLED OF TRANSMISSION LINE SECTIONALIZING AND CONTROL SWITCHES FOR EACH OF THREE SOLUTIONS OF PROBLEM PRESENTED

No. of switches	Type	Unit cost	Cost
	Solution "A"—21 local plants		
12	7,500 volts 3-pole gang operated sectionalizing air break	$ 253	$ 3,036
21	15,000 volts 3-pole gang operated sectionalizing air break	273	5,733
	Total		$ 8,769
	Solution "B"—6 local groups and plants		
4	7,500 volts 3-pole gang operated sectionalizing air break	$ 253	$ 1,012
37	15,000 volts 3-pole gang operated sectionalizing air break	273	10,101
13	25,000 volts 3-pole gang operated sectionalizing air break	308	4,004
	Total		$15,117
	Solution "C"—combined system—one plant		
21	15,000 volts 3-pole gang operated sectionalizing air break	$ 273	$ 5,733
13	50,000 volts 3-pole gang operated sectionalizing air break	568	7,384
10	50,000 volts—40 amp. oil circuit breaker complete with 50 kv. S.P. disconnects and control equipment	4,560	45,600
	Total		$58,717

TABLE 14 COST OF ELECTRIC DISTRIBUTION SYSTEMS FOR EACH OF THREE SOLUTIONS OF PROBLEMS PRESENTED

Number of towns	Number of connections per town	Voltage	Cost per town	Cost
	Solution "A"—21 local plants			
5	100	2300	$10,800	$ 54,000
4	100	6600	11,200	44,800
5	150	2300	13,350	66,750
7	150	6600	14,100	98,700
15	200	2300	16,200	243,000
5	200	6600	17,200	86,000
10	250	2300	19,000	190,000
5	500	2300	33,000	165,000
4	1000	2300	60,000	240,000
	Total			$1,188,250
	Solution "B"—6 local groups and plants			
8	100	2300	$10,800	$ 86,400
1	100	6600	11,200	11,200
10	150	2300	13,350	133,500
2	150	6600	14,100	28,200
19	200	2300	16,200	307,800
1	200	6600	17,200	17,200
8	250	2300	19,000	152,000
2	250	6600	20,250	40,500
5	500	2300	33,000	165,000
4	1000	2300	60,000	240,000
	Total			$1,181,800
	Solution "C"—combined system—one plant			
9	100	2300	$10,800	$ 97,200
11	150	2300	13,500	146,850
1	150	6600	14,100	14,100
18	200	2300	16,200	291,600
2	200	6600	17,200	34,400
10	250	2300	19,000	190,000
5	500	2300	33,000	165,000
4	1000	2300	60,000	240,000
	Total			$1,179,150

TABLE 15 TOTAL INVESTMENT FOR EACH OF THREE SOLUTIONS OF PROBLEM PRESENTED

	Solution "A"				Solution "B"				Solution "C"			
	Cost in dollars	Per cent	Cost per connection in dollars	Cost per million kw-hr. delivered per year in dollars	Cost in dollars	Per cent	Cost per connection in dollars	Cost per million kw-hr. delivered per year in dollars	Cost in dollars	Per cent	Cost per connection in dollars	Cost per million kw-hr. delivered per year in dollars
Power plants	2,484,929	56.3	158.28	126,305	1,885,220	43.5	120.08	95,821	1,236,396	27.4	78.75	62,843
Transmission lines	659,681	15.0	42.00	33,531	1,129,047	26.0	71.91	57,387	1,805,278	40.0	114.98	91,758
Transm. substations	67,329	1.5	4.29	3,422	125,654	2.9	8.00	6,387	235,933	5.2	15.03	11,992
Sectionalizing and control switches	8,769	0.2	0.56	448	15,117	0.3	0.96	768	58,717	1.3	3.74	2,984
Distribution systems	1,188,250	27.0	75.68	60,396	1,181,800	27.3	75.27	60,068	1,179,150	26.1	75.10	59,934
Total	4,408,958	100	280.81	224,102	4,336,838	100	276.22	220,431	4,515,474	100	287.60	229,511

Note: Total investment to serve to 15,700 connections 19,674,290 kw-hr. per year for each of the three solutions of the problem.

TABLE 16 ANNUAL COST OF OPERATION FOR EACH OF THE THREE SOLUTIONS OF PROBLEM PRESENTED

	Solution "A"								Solution "B"				Solution "C"
							Total				Total		
Number of plants	1	4	4	3	2	3	4		2	2	13		1
Plant identification number	1	2	3	5	6	8	11		10	12			17
Kw-hr. generated	142,600	932,300	1,519,057	1,713,157	1,782,212	3,729,142	15,034,981	24,853,449	4,406,129	9,662,956	11,015,155	25,084,240	25,255,882
Kw-hr. to plant aux.	21,600	115,200	172,800	194,400	172,800	432,000	1,104,000	2,212,800	428,400	704,000	777,600	1,910,000	1,382,400
Kw-hr. net production	121,000	817,100	1,346,257	1,518,757	1,609,412	3,297,142	13,930,981	22,640,649	3,977,729	8,958,956	10,237,555	23,174,240	23,873,482
Fuel oil used, gallons	23,767	133,186	189,882	201,548	198,024	339,013	1,366,816	2,452,236	400,557	878,450	1,001,378	2,280,385	2,295,990
Fuel oil cost at 0.03 per gal., dollars	713	3,995	5,700	6,046	5,940	10,170	41,004	73,568	12,017	26,353	30,041	68,411	68,880
Lubr. oil used, gallons	663	3,500	2,666	1,944	1,591	2,590	9,827	22,781	2,918	6,234	7,016	16,168	14,856
Lubr. oil cost, dollars	298	1,575	1,200	875	716	1,295	4,914	10,873	1,459	3,117	3,508	8,084	7,428
Plant labor, dollars	2,820	11,280	16,080	13,680	9,600	15,300	31,200	99,960	14,520	16,200	19,200	49,920	13,200
Plant supplies, dollars	200	960	1,320	1,335	1,080	2,130	4,320	11,345	1,840	2,400	2,520	6,760	3,020
Repairs to Diesel engines, dollars	612	3,028	3,960	3,315	2,300	4,464	10,752	28,431	4,110	7,104	7,992	19,206	15,840
Maint. of bldgs. and grounds, dollars	36	144	232	312	218	420	1,208	2,570	520	700	700	1,920	575
Maint. of elect. equip., dollars	87	384	420	486	382	747	1,328	3,834	580	694	772	2,046	1,135
Maint. of plant aux. equip., dollars	72	328	440	540	504	963	2,112	4,959	876	1,346	1,382	3,604	1,623
Total production cost, dollars	4,838	21,694	29,352	26,589	20,740	35,489	96,838	235,540	35,922	57,914	66,115	159,951	111,701
Cost per kw-hr. produced, cents	3.39	2.33	1.93	1.55	1.16	0.95	0.64	0.95	0.82	0.60	0.60	0.63	0.44
Maint. and oper. of transm. lines, dollars	....	....	.....	.....	.....	.....	.....	8,197	.....	.....	.....	12,998	17,901
Maint. and oper. of distrib. systems, dollars	....	....	.....	.....	.....	.....	.....	50,720	.....	.....	.....	50,720	50,720
13½ per cent fixed charges on total invest., dollars	....	....	.....	.....	.....	.....	.....	595,209	.....	.....	.....	585,473	609,589
Total oper. cost and charges, dollars	....	....	.....	.....	.....	.....	.....	889,666	.....	.....	.....	800,142	789,911
Total cost per kw-hr. del'd. to cust., cents	....	....	.....	.....	.....	.....	.....	4.52	.....	.....	.....	4.11	4.01

NOTE: Total energy delivered to consumers in each case is 19,674,290 kw-hr. per year. Cost of lubricating oil for plants numbers one to six inclusive, $0.45 per gallon; for other plants $0.50 per gallon.

the towns varying from 100 to 1000 and the towns located within an area of about 125 by 140 miles.

In solution "A" the towns to be served have been divided up into 21 different groups or individuals and are served with energy from 21 different plants. This may be called the individual plan system wherein a plant is installed in every sizable town and no attempt is made to transmit energy except in small quantities to adjacent towns.

In solution "B" the towns to be served have been divided into 6 separate groups, each one of which is served from a plant similarly located in the largest town within the group. This arrangement may be called the local group-plant system. In this system considerable use is made of transmission lines of intermediate voltage serving towns a considerable distance away from the generating plants.

In solution "C" a single plant has been installed and all towns have been interconnected by means of a transmission network system. Locations of property, plants, and transmission lines in each of the three arrangements are shown in Figs. 1, 2, and 3. All transmission lines and transmission substations have been designed with ample capacity to serve the loads indicated with voltage regulations at point of delivery within satisfactory limits. Present-day requirements in electric service are exacting to such a degree that a high standard of service is required both in regard to voltage regulation and continuity. The systems as laid out will be found to follow good engineering practice in fulfilling these requirements.

In Table 10 the results of calculations required for determination of the demand and amount of energy to be generated are shown in tabular form, and a certain plant, identified by a number which refers to Table 1, has been selected to serve each group. Load assumptions for the various customers are in accordance with data presented in Table 9. Determination of total kw-hr. to be generated and of the kw. demand on the plants involves calculations of line and transformer losses and the addition of energy used by plant auxiliaries. Loads in towns of 100 and 150 connections are single-phase, others are three-phase. The size plant required in each group is determined by the maximum kw. demand, and except in the very smallest plants, sufficient generating capacity has been provided to handle the maximum load with one generating unit out of service for repairs.

It is of interest to note that in solution "A" the total amount of energy lost in transmission and distribution is 13.1 per cent of that delivered from the plant. In solution "B" the percentage is 15.1 per cent and in solution "C" 17.6 per cent. This appears to work out in about the correct proportion found in actual operation. There will be a further loss occasioned by imperfect metering and theft of current which would raise the percentage to some little extent; however, no allowance is made in this paper for such losses.

In Tables 11 to 14 inclusive will be found tabulations of investment costs of transmission lines, transmission substations, transmission line sectionalizing and main control switches, and distribution systems for each of the three solutions. Unit-cost figures have been taken from data previously furnished in Tables 2, 3, and 4. All transmission lines have been indicated as being constructed of aluminum conductor, steel reinforced, on account of its lower cost than copper. Some slight variation in the costs of electric distribution systems for the three solutions will be found on account of changes in voltage for certain of the towns in the different group arrangements. In all instances where a step-down substation with 6600 volts or 6900 volts secondary is serving more than one town, the local distribution as well as that of other towns served has been built for 6600 volts operation, and in fact all towns served by transmission lines at 6600 volts are provided with 6600 volts distribution systems.

In Table 15 the total investment cost for each of the three solutions is summarized, and it is rather disconcerting to note that there is but slight variation of total costs in any of the three solutions. Solution "B" with the local group-plant arrangement is the least expensive with a total cost of $276 per connection, while solution "C" is the most expensive with a total cost of $297 per connection. The percentage of total investment, however, in each of the various parts of the system varies between wide limits. In solution "A" for instance, power plants constitute 56 per cent of the total investment, whereas in solution "C" they constitute only 27 per cent.

Final results of this study are embodied in annual operating-cost figures for each of the three solutions in Table 16. In this table all operating costs considered plus fixed charges on total investment have been brought together to a final figure and divided by the amount of energy delivered to the customers. In spite of the fact that plant production costs vary from 3.39 cents in the smallest plant to 0.44 cents per kw-hr. in the largest, the difference in final costs per kw-hr. delivered to customers in all solutions is rather close together. It can be pointed out that consideration has not been given to all expenses incident to operation of this group of properties inasmuch as no allowance has been made for superintendence and administrative expenses nor for meter reading, accounting, advertising, nor legal expenses. These items of expense have been purposely omitted, however, since they are not affected directly by the type of system installed. Although solution "C" shows a final figure of cost one mill lower than solution "B" there may be quite honest and well-supported differences in opinion as to which of these two solutions is the more desirable, weighing the relative hazards of transmission-line operation as against power-plant operation.

Conclusion

In conclusion it may be stated that nothing definite has been proved in regard to the use of Diesel plants. The purpose of this paper, however, has been to present representative investment and operating cost figures. If in solution "C" of the problem, a steam plant were used instead of a Diesel plant, there would likely be a slight difference in the cost per kw-hr. delivered provided the two plants used the same fuel. No doubt the steam plant could be built at considerably less cost than the Diesel plant with a resulting credit in fixed charges in the comparative operating cost statement. This credit, however, would be somewhat more than offset by the difference in cost of fuel and labor since the steam plant probably would not generate more than 7 kw-hr. per gallon of fuel and the number of plant employees would be greater.

There is a definitely established field for Diesel plants where the capacity of the plant is small, where water and cooling conditions are unfavorable for condensing turbine operation, where the site is relatively inaccessible or where space available is extremely limited. It is of more interest, however, to compare the Diesel plant with other types of plants for situations where none of the above conditions exists, strictly on a basis of operating and investment cost.

On such a basis and in cases where there is no cheaper fuel available than oil, it would appear that the Diesel plant is on par with any other type of plant, provided the engines used are of correct and satisfactory design and can be relied on for uninterrupted service when a proper maintenance schedule is followed. The success or failure of this type of prime mover, then, in the final analysis, depends on the manufacturers of the engines. Adequate engineering, suitable design, proper selection of materials, good workmanship, and a willingness to stand behind their product in operation as as well in sales promotion should establish a high and important position for Diesel engine in the power field.

Discussion

P. H. Schweitzer.[1] The paper is original, for the author does not compare the economics of Diesel oper tion with steam operation, which has been done so many times, but compares three different solutions to the problem of supplying a certain area with electricity, in all three solutions using Diesel engines for power generation. His figures and conclusions should be interesting to those who face problems of economical generation and distribution of power.

One surprising result of the author's analysis is that, in spite of the fact that plant production costs vary from 3.34 cents to 0.44 cents per kw-hr., the differences in final costs per kw-hr. delivered to customers in all solutions are rather close together.

The writer cannot help thinking, however, that the author's figures for small plants are too high and for large plants too low. Let a few items be taken in illustration: For a 120-hp. power plant the first cost is given as $33,114, or $283 per kilowatt of generating capacity. Most engineers will find this at least $100 too high. Mr. Edgar J. Kates estimated $160 per kw-hr. as the first cost of such an installation. On the other hand, the first cost of a 10,000-kw. power plant consisting of six 2400-hp. engines estimated at $122 per kilowatt sounds too optimistic.

The specific fuel consumption of a small engine is not 80 per cent greater than that of a large engine, as indicated in Table 5. The writer would suggest figures as 0.4 lb. per hp-hr. for the largest engines and 0.6 lb. per kw-hr. for the smallest. The difference is only 50 per cent in favor of the large engine and in practice is probably less.

Estimating the lubricating-oil economy as 500 kw-hr. per gal. is pessimistic enough, but the author expects only 215 kw-hr. per gal. of lubricating oil. Labor repair and maintenance costs as given are similarly somewhat discriminating against the small engine.

If one corrects for these items, the calculations of the author will show a decided preference for decentralized power, so far as Diesel engines are concerned. Solution A, employing 21 different plants, will come out economically superior to solution B and C, using 6 plants and 1 plant, respectively.

One solution of the problem was not touched upon, although it perhaps deserves consideration, and that is to use light interconnections for part or all of the base load supplied centrally and to generate part or all of the peak load locally in decentralized stations. The writer would like to know if the author gave thought to such a solution and what he thinks of it.

The adaptability of the Diesel for peak-load power generation is very clearly shown in the writer's article, "Diesel Engines for Peak Load," in *Electrical World*, Dec. 21 and 28, 1929. The figures of the author on transmission lines supplement these figures and strengthen the conclusions.

H. C. Thuerck.[2] The author has given completely and clearly a method to be used in solving the problems of power generation and distribution in territories that are comparatively sparsely populated. His paper indicates that he has gone to considerable length in order to obtain data for it. In using the information given in his treatise it should be kept in mind that these data were obtained in communities located in the South and Southwestern parts of the United States.

Author's Closure

Professor Schweitzer has raised several questions in regard to

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values and average economies reported. The first question raised is that of the cost of the Diesel plants, and the statement is made that a plant with one 60-hp. and one 120-hp. units installed should cost less than $22,000 instead of $33,114. Possibly this idea arises from the habit of thinking of costs in unit terms rather than by actual detail, and the unit cost figures in mind say that a Diesel plant should cost $160 per kw.

The plant, as estimated, is housed in a wood-frame structure with corrugated sheet-metal cover in which sufficient space has been allowed for installation of auxiliary equipment and a third unit, as well as for proper storage of plant supplies and spare parts. This building is priced at $3758, including 15 per cent overhead, and it has been erected on a lot worth $1000. Possibly the building could be erected for less money than this, but it is submitted that the margin of possible saving on this item cannot be very wide.

An item of $4777 has been included for auxiliary and accessory equipment. This item has been estimated at $3967 for material and $810 for labor and includes one 10,000-gal. fuel-oil storage tank of permanent and substantial construction; fuel-oil transfer pump, strainer and heater; two centrifugal jacket-water pumps; one cooling tower and basin; lubricating oil-storage tanks and filter; air, oil, water, and exhaust piping; one air compressor and storage tanks; foundations for all equipment included under this heading; necessary gages and thermometers; freight and handling charges.

Cost figures on the Diesel engines are based on recent quotations, and under the heading of engines there also are included freight charges, excavations, foundations, exhaust tunnels, air-intake conduits, air filters, labor of erection, and starting up.

The electric plant item consists of one 90-kva. and one 50-kva. generators, each direct-connected to their respective engines; two belt-driven exciters; one standard 2300-volt switchboard consisting of two generator panels and one feeder panel; station wiring; freight and handling charges, and labor of erection and installation.

There has been added 15 per cent overhead to all items in arriving at the total cost figure. This figure is more nearly a minimum cost than it is a maximum cost, since many refinements which might be necessary or desirable have been omitted on account of the small capacity of the plant. Refinements might consist of fireproof building construction, overhead crane, more real estate, grading and improvement of the site, sanitary plumbing, painting of building and equipment, multiple feeder circuits, underground construction for outgoing feeders, exhaust silencers, twin tanks for fuel-oil storage, closed jacket-water cooling system including heat exchangers, and lubricating-oil centrifuge.

It has further been stated that a plant equipped with six 2400-hp. units should cost more than $122 per kw. The plant as actually estimated includes all the refinements mentioned in the foregoing paragraph, and the only reason for exceeding the total cost figure given would be unusual or extraordinary expense met on account of difficulty of access to plant site, high price of real estate, necessity of building in cramped spaces, unfavorable labor conditions, freight and handling costs above average, excavations to be made in rock, and similar reasons. It is not felt therefore that the estimate is low when considering average conditions.

It should be readily appreciated that the cost of land, structures, electric plant, and auxiliaries and accessories per kilowatt or per horsepower of installed capacity will decrease quite rapidly as the size of the installation increases. Consequently, even though the cost of the engines per horsepower does not vary to any great extent, the overall cost of the complete plant per unit of installed capacity will decrease as size of plant increases. This point may be better appreciated by reference to the itemized cost of plants 1 and 17 tabulated as percentages of the total:

	Plant 1	Plant 17
Land	3.0	0.7
Structures	11.4	5.5
Engines	45.0	76.0
Electric plant	26.2	9.0
Auxiliaries and accessories	14.4	8.8

Referring to fuel and lubricating-oil economy as indicated in Table 5, there has been no discrimination against the small engine plant in favor of the large one. The figures presented are based on operating summaries maintained over a period of several years, in which the performance of 75 different units in 29 different plants is being tabulated. The figures presented are not specific economy at any particular load, but are representative of actual results obtained in the particular type and size of plant referred to. Load factors and plant-capacity factors of small plants such as Nos. 1 and 2 will average less than for larger plants due to the character of load which they are carrying. It should also be remembered that plants 1 to 6 inclusive are powered with two-cycle, solid-injection engines of the crankcase-scavenging type, and the specific economy of this type engine, both in regard to fuel and lubricants, is much below that of the type engines used in the larger plants. Fuel economy remains constant in plants 7 to 17 inclusive, and improvement in lubricating-oil economy from 800 kw. capacity to 10,000 kw. is indicated as only 18 per cent. In any case economies shown are those which have actually been experienced and which may reasonably be expected in similar installations.

Data presented in Table 16 will not support the contention that solution "A" of the problem is economically superior to solutions "B" and "C," and it is not thought that any advantage can be demonstrated for decentralized power. A case has been presented, however, for thorough and complete analysis of each individual problem of generation and distribution rather than to follow a predetermined and fixed policy in regard to such developments. In this particular case the difference of a half cent in final cost and charges per kilowatt-hour delivered to the customers between solutions "A" and "C" may represent all or more than the entire amount of the net profit in the operation of the properties.

In preparation of Table 16 fixed charges have been taken arbitrarily as 13½ per cent of the total investment. These charges may be detailed as follows:

Interest	7.50
Insurance	0.33
Taxes	0.67
Replacements	5.00
Total	13.50

Interest charges may be considered as constant for all of the individual parts which make up the fixed capital investment. Even though accounting procedure may treat the other elements of the fixed charges in the same way, there is an actual difference in depreciation, insurance, and taxes between the individual parts of the investment. In other words, in respect to fixed charges certain parts of the total investment are more desirable than others, and those parts are the ones on which insurance, taxes, and depreciation actually realized are a minimum. It can be readily appreciated that a dollar spent in construction of a building of fireproof design which will have a probable life of 50 years is better invested than one spent in construction of a wood-frame structure with a probable life of 20 years.

Fire and windstorm insurance rates are lower on plants of fireproof construction than they are on those of wood-frame or

TABLE 17 ANTICIPATED ACTUAL DEPRECIATION IN EACH OF THE THREE SOLUTIONS OF THE PROBLEM PRESENTED

Depreciation, rate, in per cent	Description	Solution "A" Investment	Solution "A" Annual depreciation	Solution "B" Investment	Solution "B" Annual depreciation	Solution "C" Investment	Solution "C" Annual depreciation
0	Power-plant land	$ 47,000	$	$ 24,000	$	$ 8,000	$ ....
5	Power-plant structures, wood frame	45,642	2,282	.....	....	.....	....
3	Power-plant structures, steel and asbestos	104,514	3,135	.....	....	.....	....
2	Power-plant structures, steel and brick	144,860	2,896	232,224	4,644	68,668	1,373
6	Engines	1,429,330	85,759	1,183,856	71,031	938,023	56,281
5	Electric plant	383,277	19,164	204,816	10,241	113,492	5,675
6	Auxiliaries and accessories	330,306	19,818	204,324	14,419	108,213	6,493
0	Transmission-line land	135,181	....	188,037	....	203,981	....
2	Transmission-line overhead conductors	206,900	4,138	460,086	9,202	1,033,935	20,679
5	Transmission-line poles, towers, and fixtures	317,600	15,880	480,924	24,046	567,362	28,368
5	Transmission substations	67,329	3,366	125,654	6,283	235,933	11,797
5	Transmission sectionalizing and control switches	8,769	438	15,117	756	58,717	2,936
5	Overhead distribution systems	1,188,250	59,413	1,181,800	59,090	1,179,150	58,958
	Total	$4,408,958	$216,289	$4,336,838	$199,712	$4,515,474	$192,560
	Average depreciation		4.9%		4.6%		4.25%

merely fire-resisting construction. As a consequence, insurance costs for solution "C," in which plant investment is only half that of solution "A" and in which fireproof construction has been used, will be lower than those for solution "A" by as much as 1 per cent of the total annual costs and charges. Insurance cost for solution "B" will be about half that for solution "A."

In the matter of taxes, experience has shown that plants will be assessed at a higher percentage of their actual value than lines will be. This fact works to the advantage of the centralized system in which the percentage of the total investment which has been spent on plants is much less than that for the decentralized system, and as a consequence the assessment for taxation will be much less in proportion. This may account for a difference of as much as 1 to 1½ per cent of the total annual costs and charges.

Taking up the matter of depreciation actually realized, Table 17 has been prepared in which the investment, under each of the three solutions, has been broken down into its component parts and representative straight-line depreciation rates have been applied to each part. The results speak for themselves and indicate decided advantages for the combined system over the local plant system by as much as 3 per cent of the total annual operating costs and charges.

Professor Schweitzer has suggested that a desirable solution might be arrived at by use of several interconnected plants, one of which is designed to carry a base load while the others are used only on the peaks. There would be advantages in such an arrangement, but in the case of the particular problem in hand no economic advantage can be shown for it. If, for example, solution "C" were modified to the extent of providing one base-load plant to handle about 4000-kw. load and two peak-load plants each to handle about 1400-kw. load, the base-load plant would be No. 15 and the peak-load plant No. 12. The cost of these three plants would be $219,572 more than that for the one No. 17 plant. Transmission-line investment avoided in this arrangement would amount to changing the conductor on 100 miles of 44-kv. line from No. 1/0 A.C.S.R. to No. 2 A.C.S.R. at a saving of $185 per mile and also a change of conductor on 197 miles of 44-kv. transmission line from No. 4/0 to No. 2 at a saving of $1061 per mile. The total saving in transmission-line costs would amount to $227,517, or about $8000 more than the additional cost of the generating plants. This means that from an investment standpoint practically no saving has been effected. From an operating standpoint, however, the original solution is to be preferred, since the difference in operating labor alone will amount to $10,000 a year.

Report on Oil-Engine Power Cost for 1929[1]

THIS REPORT contains information covering 36 oil-engine plants, which submitted data sufficiently complete to permit calculation of total power-production cost. Questionnaires were sent to 106 plants, and the replies to these questionnaires may be classified as follows:

	Plants
Complete data furnished, tabulated in this report	36
Insufficient data submitted	13
Unable to furnish data	9
Engines not operated	3
No engines installed	1
No replies to questionnaires	41
Reported under other serial numbers	3
Total number to which questionnaires were sent for 1929	106

Questionnaires were sent in 1929 to all plants which had submitted sufficiently complete data for the preceding period, which data were contained in last year's report. The method followed in the preceding report of identifying plants by numbers was retained in the present report, identical serial numbers shown in both reports representing the same plants.

Period Covered. Most of the data submitted refer to the calendar year 1929, though a few reports are based on other periods.

Output Represented. The total *net* output for the thirty-six plants listed in this report amounts to 134,766,761 kw-hr.

Questionnaire. The questionnaire sent to the various plants in 1929 differs in many respects from that which was sent out in the preceding year, principally in that it contained a number of additional questions.

Minimum Data Required. Although some of the plants were unable to supply information covering each and every question listed in the questionnaire, the data submitted by such plants were incorporated in this report provided the minimum required information was contained in their replies.

No attempt was made to differentiate between well-run and poorly run plants. Reference is made, however, in this report to the lowest cost charges for fuel oil, lubricating oil, attendance, and repairs for three groups of plants having rated capacities of 2000 b.hp. and over, 1000 to 2000 b.hp., and less than 1000 b.hp., respectively. Results obtained from all plants which were considered explicit, correct, and sufficiently complete to permit calculation of power cost are included in this report. That at least the following question of the questionnaire had to be answered was considered the criterion for listing plant data in this report. The numbers are the question numbers as appearing in the questionnaire, followed by the data required.

1 Name and address of plant
4 Period covered by data
6 Type: Two or four cycle, air or mechanical injection, vertical or horizontal
7 Rated power: B.hp. or kw.
8 Number of cylinders
9 Diameter of cylinders, in.
10 Stroke, in.
11 Rated revolutions per minute
13 Type of drive (i.e., direct-connected, belt, rope, etc.)
14 Driven unit (i.e., generator, pump, lineshaft, etc.)
17 Output of each engine during period, kw-hr.
18 Net output of entire plant during period, kw-hr.
22 Peak load on entire plant during period, kw.
26 Fuel oil: Total cost for period covered, number of gallons used by entire plant
27 Lubricating oil: Total cost for period covered, number of gallons used by entire plant
28 Attendance: Total cost for period covered
29 Supplies: Total cost of all supplies used in period covered
30 Repairs: Total repairs for entire plant in period covered.

Basis for Costs and Performances. Cost figures per power unit referred to in this report are based on net kw-hr.

The term "net kw-hr. output" as used in this report is defined as the difference between the total gross output in kw-hr. of the individual units of the plant and the power in kw-hr. required for plant auxiliaries and for station lights.

Figures of power output per gallon of fuel oil and of lubricating oil are based on the gross output of the individual units or plants.

Load and capacity factors are based on gross kw-hr. output.

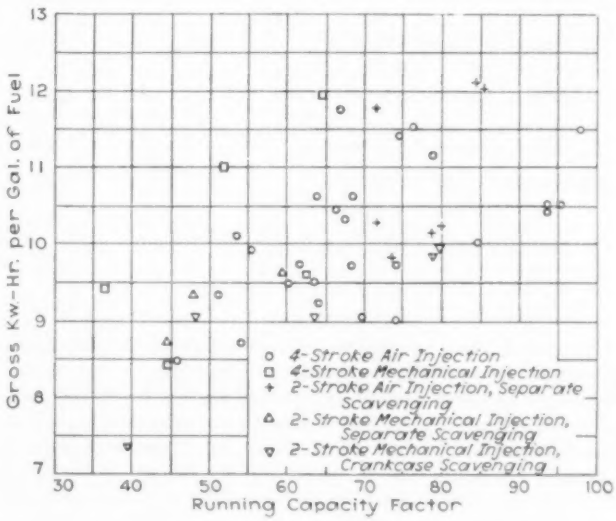


FIG. 1 FUEL ECONOMY OF DIESEL ENGINES
(This covers 37 individual units and 9 plant averages of 24 units.)

Formulas defining running engine capacity factor, running plant capacity factor, annual plant load factor, and plant service factor are as follows:

$$\text{Running engine capacity factor, per cent} = \frac{\text{Engine output in gross kw-hr.} \times 100}{\text{Kw. rating} \times \text{hours operated}}$$

$$\text{Running plant capacity factor, per cent} = \frac{\text{Plant output in gross kw-hr.} \times 100}{\text{Total rated kw-hr. of individual units}}$$

$$\text{Annual plant load factor, per cent} = \frac{\text{Plant output in gross kw-hr.} \times 100}{\text{Plant peak load in kw.} \times \text{hours in period}}$$

$$\text{Plant service factor, per cent} = \frac{\text{Total rated kw-hr. of individual units} \times 100}{\text{Total installed kw.} \times \text{hours in period}}$$

Kilowatt ratings given in the tabulation are those shown on the nameplates of the generators as reported by the operators, except in the case of plant No. 46, the generator nameplate ratings for which are evidently too low.

Answers to questions 1 to 14, inclusive, can be supplied readily by every oil-engine operator. Replies received to questions 1, 2, 3, and 5 were filed by the committee, but not published.

[1] Submitted by the Sub-Committee on Oil Engine Power Cost, Oil and Gas Power Division, A.S.M.E., Franz Eder, Chairman; Engineer, Robert W. Hunt Company, New York, N. Y.

Presented at the Third National Oil and Gas Power Meeting, State College, Pa., June 12 to 14, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Replies to questions 13 and 14 are not shown in the tabulation, all the data applying to direct-connected electric-generator units. All engines referred to in the tabulation of this report are of vertical construction.

The report incorporates information obtained in reply to questions 23, 24, and 25 pertaining to liner wear, piston cooling, and use of air filters. An attempt at drawing conclusions from this information has not yet been made at this time. These questions have been asked in the belief that the information obtained over a period of years may permit of conclusive interpretation.

Fuel-Oil Data. Questions contained in the 1929 questionnaire under heading "Fuel Oil" include those relating to the physical properties of the oil and are in line with the work of the A.S.M.E. Special Research Committee on Diesel Fuel-Oil Specifications. Although complete information on physical properties of the fuel oil has not been available in many cases, it is felt that the listing of these questions in the questionnaire serves to draw the operators' attention to the importance of these properties, and in view of its educational value a continuance of this policy is strongly recommended.

An analysis of the data submitted on fuel oil is as follows:

Prices paid for fuel oil:	Cents per gal.
Price range	2.15 to 6
Arithmetical average of prices	4.19
Weighted average of prices	4.18
Fuel-oil costs per net kw-hr.:	**Mills**
Arithmetical average of all plants	4.729
Weighted average of all plants	4.139
Lowest fuel-oil costs per kw-hr.:	**Mills**
a Plants of 2000 total b.hp. and over: Plant No. 92	2.199
b Plants of 1000 to 2000 total b.hp.: Plant No. 11	2.116
c Plants containing less than 1000 total b.hp.: Plant No. 99	2.683

The chart (Fig. 1) shows the fuel consumption for various types of engines expressed as the number of gross kilowatt-hours produced per gallon of fuel oil and plotted against the running capacity factor. The points plotted cover the individual engines in plants Nos. 2, 3, 10, 11, 13, 26, 43, 45, 46, 52, 67, and 68, and plant averages for plants Nos. 7, 24, 91, 92, 93, 94, 95, 97, and 102. Not included in this chart are corresponding data for plants for which only the plant average is available and which have engines of different types.

Lubricating Oil. An analysis of the data submitted on lubricating oil is as follows:

Prices paid for lubricating oil:	Cents per gal.
Price range	37.9 to 85.5
Arithmetical average of prices	52.1
Weighted average of prices	51.5
Lubricating-oil costs per net kw-hr.:	**Mills**
Arithmetical average of all plants	0.858
Weighted average of all plants	0.516
Lowest lubricating-oil costs per net kw-hr.:	**Mills**
a Plants of 2000 total b.hp. and over: Plant No. 45	0.092
b Plants of 1000 to 2000 total b.hp.: Plant No. 95	0.319
c Plants containing less than 1000 total b.hp.: Plant No. 99	0.413

It is interesting to note that plant No. 99 has not only the lowest fuel cost, but also the lowest lubricating-oil cost in its division.

Engine hours operated were reported by 29 of the 36 plants.

A summary of the data submitted by these 29 plants is given in the following list:

Total installed b.hp. (rated)	57,995
Total installed kw. (rated)	40,176
Total rated hp-hr. operated	276,151,590
Total gross kw-hr. produced	130,490,331
Total gallons of lubricating oil used	123,214
Rated hp-hr. per gal. of lubricating oil:	
Arithmetical average	2,400
Weighted average	2,242
Gross kw-hr. per gal. of lubricating oil:	
Arithmetical average	1,093
Weighted average	1,058

The average operating time for the engines of these 29 plants was 4760 hr., which corresponds to a weighted average running capacity factor of 68.3 per cent.

The data given in Table 1 are rearranged below according to engine types:

Plant and engine	Rated b.hp.	Rated b.hp-hr. per gal. of lubricating oil	Running capacity factor	Kw-hr. per gal. of lubricating oil	Lubricating oil purification[a]
Four-Stroke Cycle, Air Injection, Crosshead					
43-e	1000	1238	60.2	522	BC,S&C
43-f	1000	1178	63.7	525	BC,S&C
45-c	750	13125	67.6	5920	BC,S&C
45-d	1150	18365	74.5	9530	BC,S&C
45-e	1150	18380	76.2	9750	BC,S&C
52-a,b,c	3330	3575	65.3	1587	BC
Four-Stroke Cycle, Air Injection, Trunk Piston					
43-a	500	603	74.2	268	BC,S&C
43-b	500	649	68.5	267	BC,S&C
43-c	520	1024	74.2	511	BC,S&C
43-d	520	813	69.9	382	BC,S&C
45-a	600	2345	53.7	839	BC,S&C
45-b	600	2348	55.4	869	BC,S&C
2-a,b,c	3450	1828	94.4	1200	CC
3-c	800	2246	54.1	821	BC,S&C
10-a	750	1214	78.9	639	CC
11-a	750	1392	84.8	787	CC
11-b	600	1068	98.0	705	CC
13-a	275	2177	61.9	858	CC&S
13-b	200	2190	64.2	880	CC&S
13-c	750	2245	45.7	685	CC&S
94-a,b	1200	1973	67.0	904	CC&S
97-a,b,c	1020	1000	51.1	345	BC
Four-Stroke Cycle, Mechanical Injection, Trunk Piston					
91-a,b,c,d	3450	4264	52.0	1556	CC
3-a	400	1075	116.2	860	BC,S&C
3-d	1125	5375	36.2	1296	BC,S&C
24-7-a,b,c,d,	1830	3540	64.8	1478	BC.
a,b	400	1548	44.9	473	None
26-a	330	1113	62.9	467	BC
Two-Stroke Cycle, Air Injection, Crosshead, Separate Scavenging					
43-g	3750	2205	71.2	1088	BC,S&C
43-h	3750	1450	69.7	754	BC,S&C
46-a,b,c,d	6900	3640	83.3	2065	CC&S
92-a,b	2500	2237	71.6	1152	BC&S
10-b	750	1321	73.8	649	CC
Two-Stroke Cycle, Mechanical Injection, Trunk Piston, Separate Scavenging					
93-a,b,c	1960	3750	44.8	1146	CC
95-a,b	1120	4762	48.0	1532	CC
Two-Stroke Cycle, Mechanical Injection, Trunk Piston, Crankcase Scavenging					
68-a	240	1572	48.1	442	CC
68-b	360	1885	63.4	831	CC
67-a	360	2066	78.8	1130	S
67-b	360	2113	79.4	1165	S
102-a,b	480	1210	39.8	321	BC&S

[a] For key see notes at foot of Table 1.

Plants containing some semi-Diesel power are not included in this tabulation, although they furnished information which permits the calculation of plant rated horsepower-hours per gallon.

Nor are any plants included the results for which are averaged for several different types of Diesel engines. Engine No. 68-e was not included because of the high ratio of the amount of initial filling of the crankcase to the oil used.

The questionnaire did not cover the filtering of lubricating oil, and it may be assumed that oil was filtered where the tabulations do not indicate any purification of lubricating oil.

Table 1 - Information Covering Lubricating Oil

Plant Number	Engine Designation	Engine Cycle	Injection System*	Scavenging System**	Trunk Piston or Cross Head	Rated B.H.P.	Number of Cylinders	Cylinder Bore - Inches	Stroke - Inches	Rated R.P.M.	Generator Rating - K.W.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Rated Horsepower Hours in Reported Period	Gallons of Lubricating Oil Used	Rated H.P.Hrs. per Gallon of Lubricating Oil	Running Engine Capacity Factor (See Text)	Running Plant Capacity Factor (See Text)	Gross Output - K.W.Hrs.	Gross K.W.Hrs. per Gallon of Lubricating Oil	Lubricating Oil Treatment***	Average Cost of Lubricating Oil - Cents per Gallon
43	a	4	A	-	TP	500	3	22	29-1/2	150	300	1915	735	367,500	609	603	74.2		163,576	268	BC,	
	b	4	A	-	TP	500	3	22	29-1/2	150	300	1916	1,216	608,000	937	649	68.5		249,744	267	S,	
	c	4	A	-	TP	520	4	19	24-1/2	200	350	1919	1,631-1/2	849,000	829	1,024	74.2		423,410	511	&C	
	d	4	A	-	TP	520	4	19	24-1/2	200	350	1920	1,476-1/2	768,000	945	813	69.9		361,094	382	"	
	e	4	A	-	CH	1,000	6	20-1/2	36	150	700	1922	2,355-1/2	2,355,500	1,899	1,238	60.2		993,320	522	"	
	f	4	A	-	CH	1,000	6	20-1/2	36	150	700	1925	1,760-1/2	1,760,500	1,493	1,178	63.7		785,040	525	"	
	g	2	A	S	CH	3,750	6	30	42	124	2,600	1928	7,302-1/2	27,370,000	12,408	2,205	71.2		13,500,800	1,088	"	
	h	2	A	S	CH	3,750	6	30	42	124	2,800	1929*	3,782-1/4	14,176,000	9,783	1,450	69.7		7,375,600	754	"	
	Plant					11,540					8,100			48,254,500	28,903	1,669		69.9	23,852,584	825		53.5
46	a	2	A	S	CH	1,250	5	20-3/4	26	180	850*	1922	5,938	7,422,500	---	---	80.0		4,034,500	--	CCAS	
	b	2	A	S	CH	1,250	5	20-3/4	26	180	850*	1922	4,300	5,375,000	---	---	78.9		2,885,000	--	"	
	c	2	A	S	CH	2,200	4	28	44	120	1,500*	1922	7,651	16,832,200	---	---	84.3		9,671,200	--	"	
	d	2	A	S	CH	2,200	4	28	44	120	1,500*	1922	7,481	16,458,200	---	---	85.1		9,555,200	--	"	
	Plant					6,900					4,700			46,087,900	12,653	3,640		83.3	26,145,900	2,065		37.9
45	a	4	A	-	TP	600	6	16-1/2	24	200	400	1923	1,286	771,600	329	2,345	53.7		276,000	839	BC,	
	b	4	A	-	TP	600	6	16-1/2	24	200	400	1923	1,265	759,000	323	2,348	55.4		280,550	869	SAC	
	c	4	A	-	CH	750	4	23	32	150	500	1923	2,451	1,838,250	140	13,125	67.6		828,850	5,920	"	
	d	4	A	-	CH	1,150	6	23	32	150	800	1926	5,575	6,411,250	349	18,365	74.5		3,325,250	9,530	"	
	e	4	A	-	CH	1,150	6	23	32	150	800	1926	5,468	6,288,200	342	18,380	76.2		3,334,750	9,750	"	
	Plant					4,250					2,900			16,068,300	1,483	10,830		72.5	8,045,400	7,430		46.0
2	a	4	A	-	TP	1,150	6	23	29	166-2/3	800	1925	7,829-1/4	9,003,600	---	---	95.3		5,971,810	--	CC	
	b	4	A	-	TP	1,150	6	23	29	166-2/3	800	1925	7,500-1/4	8,625,300	---	---	93.8		5,628,360	---	"	
	c	4	A	-	TP	1,150	6	23	29	166-2/3	800	1925	6,859-3/4	7,888,300	---	---	93.9		5,162,810	---	"	
	Plant					3,450					2,400			25,517,200	13,956	1,828		94.4	16,752,980	1,200		39.3
91	a	4	M	-	TP	1,125	6	22	30	180	800	1927	8,469	9,527,600	---	---	49.3		3,341,525	---	CC	
	b	4	M	-	TP	1,125	6	22	30	180	800	1928	6,615	7,441,900	---	---	49.6		2,628,075	---	"	
	c	4	M	-	TP	600	6	17	24	225	400	1927	4,329	2,597,400	---	---	60.7		1,050,925	---	"	
	d	4	M	-	TP	600	6	17	44	225	400	1927	3,778	2,266,800	---	---	62.3		941,475	---	"	
	Plant					3,450					2,400			21,833,700	5,118	4,264		52.0	7,962,000	1,556		71.4
52	a	4	A	-	CH	830	4	23	32	164	560	1928	762	632,460	---	---	68.5		292,400	---	BC	
	b	4	A	-	CH	1,250	6	23	32	164	850	1928	4,559	5,698,750	---	---	66.5		2,576,900	---	"	
	c	4	A	-	CH	1,250	6	23	32	164	850	1928	5,441	6,801,250	---	---	63.9		2,958,600	---	"	
	Plant					3,330					2,260			13,132,460	3,673	3,575		65.3	5,829,900	1,587		85.5
3	a	4	M	-	TP	400	6	14-1/2	18	277	275	1923	860	344,000	320	1,075	116.2		275,000	860	BC,S	
	b	4	A	-	TP	800	8	17	24	200	540	1924	0	0	0	---	--		0	--	& C	
	c	4	A	-	TP	800	8	17	24	200	540	1926	2,190	1,752,000	780	2,246	54.1		640,000	821	"	
	d	4	M	-	TP	1,125	6	22	30	180	750	1927	7,008	7,884,000	1,466	5,375	36.2		1,900,000	1,296	"	
	Plant					3,125					2,105			9,980,000	2,566	3,886		42.2	2,815,000	1,097		49.6
92	a	2	A	S	CH	1,250	5	20-3/4	26	180	900	1928	5,910	7,390,000	---	---	74.2		3,948,900	---	BCAS	
	b	2	A	S	CH	1,250	5	20-3/4	26	180	900	1928	4,879	6,099,000	---	---	68.3		3,002,900	---	"	
	Plant					2,500					1,800			13,489,000	6,030	2,237		71.6	6,949,800	1,152		60.5
41	a	4	A	-	TP	520	3	22	29-1/2	164	400	1922	---	---	---	---	---		---	--	CCAS	
	b	4	A	-	TP	700	4	22	29-1/2	164	500	1923	---	---	---	---	---		---	--	"	
	c	4	A	-	TP	1,150	6	23	29-1/2	164	900	1928	---	---	---	---	---		---	--	"	
	Plant					2,370					1,800				2,902	---		--	3,820,810	1,316		62.5
5	a	2	M	S	TP	720	6	16	20	257	480	---	---	---	---	---	---		---	---	---	
	b	2	M	S	TP	720	6	16	20	257	480	---	---	---	---	---	---		---	---	---	
	c	2	M	S	TP	720	6	16	20	257	480	---	---	---	---	---	---		---	---	---	
	Plant					2,160					1,440				1,142	---	---	--	406,230	356		49.4
6	a	2	M	CC	TP	300	6	14	17	257	200	1926	---	---	---	---	---		---	--	---	
	b	4	A	-	TP	600	6	17	25	200	400	1926	---	---	---	---	---		---	---	---	
	c	4	A	-	TP	600	6	17	25	200	412	1927	---	---	---	---	---		---	---	---	
	d	4	A	-	TP	600	6	17	25	200	412	1928	---	---	---	---	---		---	---	---	
	Plant					2,100					1,424				1,761	---		--	1,356,500	770		53.6

Table 1 - Information Covering Lubricating Oil

Plant Number	Engine Designation	Engine Cycle	Injection System*	Scavenging System**	Trunk Piston or Cross Head	Rated B.H.P.	Number of Cylinders	Cylinder Bore - Inches	Stroke - Inches	Rated R.P.M.	Generator Rating - K.W.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Rated Horsepower Hours in Reported Period	Gallons of Lubricating Oil Used	Rated H.P.Hrs. per Gallon of Lubricating Oil	Running Engine Capacity Factor (See Text)	Running Plant Capacity Factor (See Text)	Gross Output - K.W.Hrs.	Gross K.W.Hrs. per Gallon of Lubricating Oil	Lubricating Oil Treatment***	Average Cost of Lubricating Oil - Cents per Gallon
93	a	2	M	S	TP	560	4	16	20	257	376	1928	4,933	2,762,500	---	---	51.4		954,200	---	CC	
	b	2	M	S	TP	700	5	16	20	257	480	1928	4,966	3,476,200	---	---	49.0		1,167,900	---	"	
	c	2	M	S	TP	700	5	16	20	257	480	1928	5,676	3,973,200	---	---	36.6		996,600	---	"	
	Plant					1,960					1,336			10,211,900	2,721	3,750		44.8	3,118,700	1,146		54.0
7	a	4	M	-	TP	360	6	11-1/2	16	277	225	1925	3,587-1/2	1,291,500	---	---	67.3		543,000	--	BC	
	b	4	M	-	TP	360	6	11-1/2	16	277	225	1925	4,461	1,606,000	---	---	62.4		626,300	--	"	
	c	4	M	-	TP	360	6	11-1/2	16	277	225	1925	4,597-1/2	1,655,100	---	---	65.9		682,000	--	"	
	d	4	M	-	TP	750	6	16	22	257	500	1927	5,265-1/2	3,949,100	---	---	64.5		1,696,100	--	"	
	Plant					1,830					1,175			8,501,700	2,400	3,540		64.8	3,549,400	1,478		48.0
18	a	2	M	CC	CH	450	5	15-1/4	16	275	300	1922	--	---	---	---	--		---	--	--	
	b	4	A	-	TP	600	6	17	25	200	410	1926	--	---	---	---	--		---	--	--	
	c	4	A	-	TP	600	6	17	25	200	410	1928	--	---	---	---	--		---	--	--	
	Plant					1,650					1,120				1,902	---		--	2,448,290	1,286		51.1
10	a	4	A	-	TP	750	4	22	29	166-2/3	500	1924	1,558	1,168,500	962	1,214	78.9		614,700	639	CC	
	b	2	A	S	CH	750	4	17	27	176-1/2	500	1925	7,001	5,250,750	3,975	1,321	73.8		2,582,180	649	"	
	Plant					1,500					1,000			6,419,250	4,937	1,299		74.7	3,196,880	647		61.7
11	a	4	A	-	TP	750	4	22	29	166-2/3	500	1924	144-3/4	108,570	78	1,392	84.8		61,390	787	CC	
	b	4	A	-	TP	600	6	16-1/2	24	200	404	1926	2,560-3/4	1,536,450	1,437	1,068	98.0		1,013,600	705	"	
	Plant					1,350					904			1,645,020	1,515	1,086		97.1	1,074,990	709		44.6
13	a	4	A	-	TP	275	4	13-1/2	19-1/2	257	175	1923	6,052	1,664,300	764	2,177	61.9		655,200	858	CC&S	
	b	4	A	-	TP	200	3	13-1/2	19-1/2	257	125	1923	3,125	625,000	285	2,190	64.2		250,900	880	"	
	c	4	A	-	TP	750	4	23	29-1/2	164	500	1925	1,870	1,402,500	624	2,245	45.7		427,400	685	"	
	Plant					1,225					800			3,691,800	1,673	2,206		55.9	1,333,500	797		40.0
94	a	4	A	-	TP	600	6	17	24	200	410	1927	5,660	3,396,000	---	---	67.2		1,558,490	--	CC&S	
	b	4	A	-	TP	600	6	17	24	200	410	1927	5,712	3,427,200	---	---	66.7		1,564,570	--	CC&S	
	Plant					1,200					820			6,823,200	3,456	1,973		67.0	3,123,060	904		47.7
17	a	4	A	-	TP	600	6	17	25	200	410	1926	--	---	---	---	--		---	---	--	
	b	4	A	-	TP	600	6	17	25	200	410	1926	--	---	---	---	--		---	---	--	
	Plant					1,200					820				1,466	---		--	1,667,688	1,137		57.8
68	a	2	M	CC	TP	240	4	14	17	257	140	1925	4,480	1,075,200	683	1,572	48.1		301,673	442	CC	
	b	2	M	CC	TP	360	6	14	17	257	250	1925	5,092	1,833,120	972	1,885	63.4		807,120	831	CC	
	c	2	M	S	TP	560	4	16	20	257	375	1928	355	198,800	629[3]	316[3]	59.1		78,700	125[3]	BC	
	Plant					1,160					765			3,107,120	2,284	1,358		58.4	1,187,493	519		52.9
95	a	2	M	S	TP	560	4	16	20	257	375	1929[2]	5,135	2,875,600	---		47.2		910,500	--	CC	
	b	2	M	S	TP	560	4	16	20	257	375	1929[2]	4,994	2,796,640	---		48.7		912,600	--	CC	
	Plant					1,120					750			5,672,240	1,190	4,762		48.0	1,823,100	1,532		46.0
96	a	4	M	-	TP	600	6	17	24	225	400	1925	3,206	1,923,000	---	---	41.5		532,200	--	None	
	b	4	M	-	TP	300	3	17	24	225	200	1923	5,091	1,527,300	---	---	58.6		596,400	--	None	
	c	2	M	CC	TP	200[1]	4	14	17	257	136	1921	968	193,600	---	---	50.3		66,200	--	None	
	Plant					1,100					736			3,643,900	2,220	1,642		49.1	1,194,800	538		50.3
97	a	4	A	-	TP	520	4	19	24	200	333	1915	5,383	2,799,200	---	---	--		---	--	BC	
	b	4	A	-	TP	250	4	13-3/4	17-1/2	257	150	1914	7,530	1,882,500	---	---	--		---	--	BC	
	c	4	A	-	TP	250	4	13-3/4	17-1/2	257	210	1914	5,638	1,409,500	---	---	--		---	--	BC	
	Plant					1,020					693			6,091,200	6,093	1,000		51.1	2,097,440	345		50.4
98	a	2	M	CC	TP	360	6	14	17	257	240	1926	6,342	2,283,100	---	---	60.6		923,400	--	BC	
	b	2	M	CC	TP	360	6	14	17	257	240	1929[4]	2,564	923,040	---	---	68.2		419,400	--	BC	
	c	2	M	CC	TP	180	3	14	17	257	120	1928	4,623	832,340	---	---	65.9		365,650	--	BC	
	d	2	M	CC	TP	100[1]	2	14	17	257	65	---	1,527	152,700	---	---	57.9		57,460	--	BC	
	Plant					1,000					665			4,191,180	3,483	1,203		63.2	1,765,910	507		50.4
100	a	2	M	CC	TP	300[1]	6	14	17	257	200	1923	3,169	950,700	---	---	60.9		386,000	--	BC	
	b	2	M	CC	TP	240	4	14	17	257	160	1924	5,346	1,283,000	---	---	55.3		472,700	--	BC	
	c	2	M	CC	TP	200[1]	4	14	17	257	136	1924	5,274	1,054,800	---	---	64.4		462,100	--	BC	
	Plant					740					496			3,288,500	2,123	1,547		59.9	1,320,800	622		42.6
67	a	2	M	CC	TP	360	6	14	17	257	250	1925	3,030	1,090,800	528	2,066	78.8		596,800	1,130	S	
	b	2	M	CC	TP	360	6	14	17	257	250	1925	2,877	1,035,720	490	2,113	79.4		571,000	1,165	S	
	Plant					720					500			2,126,520	1,018	2,088		79.1	1,167,800	1,148		62.8

Table 1 - Information Covering Lubricating Oil

Plant Number	Engine Designation	Engine Cycle	Injection System*	Scavenging System**	Trunk Piston or Cross Head	Rated B.H.P.	Number of Cylinders	Cylinder Bore - Inches	Stroke - Inches	Rated R.P.M.	Generator Rating - K.W.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Rated Horsepower Hours in Reported Period	Gallons of Lubricating Oil Used	Rated H.P.Hrs. per Gallon of Lubricating Oil	Running Engine Capacity Factor (See Text)	Running Plant Capacity Factor (See Text)	Gross Output - K.W.Hrs.	Gross K.W.Hrs. per Gallon of Lubricating Oil	Lubricating Oil Treatment***	Average Cost of Lubricating Oil - Cents per Gallon
19	a	2	M	CC	TP	100[1]	2	14	17	257	60	--	--	---	---	---	--		---	---	--	
	b	2	M	CC	CH	240	4	12-1/2	13-1/4	325	160	1927	--	---	---	---	--		---	---	--	
	c	2	M	CC	CH	360	4	15-1/4	16	275	240	1927	--	---	---	---	--		---	---	--	
	Plant					700					460			---	1,556	---		--	853,520	420		54.4
99	a	4	A	-	TP	400	4	17	24	200	275	1927	6,659	2,663,600	---	---	73.3		1,342,100	--	CC&S	
	b	2	M	CC	TP	200'	4	14	17	257	160	--	448	89.600	---	---	65.3		46,800	--	CC&S	
	Plant					600					435			2,753,200	1,239	2,220		72.9	1,388,900	1,120		45.3
106	a	4	A	-	TP	600	6	17	25	200	410	1929[4]	--	---	943	---	--	--	767,710	814	--	52.2
101	a	2	M	CC	TP	240	4	14	17	257	160	1926	5,118	1,228,300	---	---	57.0		466,940	--	BC&S	
	b	2	M	CC	TP	150[3]	3	14	17	257	120	1919	2,972	445,800	---	---	40.7		145,040	--	BC&S	
	c	2	M	CC	TP	150[3]	3	14	17	257	100	--	1,633	244,950	---	---	66.2		108,136	--	BC&S	
	Plant					540					380			1,919,050	1,837	1,044		53.7	720,116	392		51.9
102	a	2	M	CC	TP	240	4	14	17	257	160	1928	5,109	1,226,160	---	---	40.4		329,900	--	BC&S	
	b	2	M	CC	TP	240	4	14	17	257	160	1928	5,089	1,216,560	---	---	39.3		316,800	--	BC&S	
	Plant					480					320			2,442,720	2,019	1,210		39.8	646,700	321		46.0
104	a	2	M	CC	TP	120	2	14	17	257	72	--	7,367	884,040	---	---	75.5		400,440	--	None	
	b	2	M	CC	TP	120	2	14	17	257	72	--	4,592	551,040	---	---	56.0		185,390	--	None	
	c	2	M	CC	TP	100[3]	2	14	17	257	60	--	7,383	738,300	---	---	63.6		281,980	--	None	
	d	2	M	CC	TP	75[3]	2	12	15	300	48	--	6,753	506,475	---	---	82.4		267,080	--	None	
	Plant					415					252			2,679,855	3,151	852		69.7	1,134,890	360		54.0
24	a	4	M	-	TP	200	3	14-1/2	18	277	136	1925	5,110	1,022,000	660	1,548	46.9		325,900	494	None	
	b	4	M	-	TP	200	3	14-1/2	18	277	136	1925	5,110	1,022,000	660	1,548	42.9		297,900	451	*	
	Plant					400					272			2,044,000	1,320	1,548		44.9	623,800	473		43.0
103	a	2	M	CC	TP	240	4	14	17	257	160	--	6,030	1,447,300	---	---	51.8		499,600	--	None	
	b	2	M	CC	TP	150[3]	3	14	17	257	100	--	5,782	867,300	---	---	55.8		322,680	--	None	
	Plant					390					260			2,314,600	1,416	1,634		53.3	822,280	581		54.0
105	a	2	M	CC	TP	150[3]	3	14	17	257	100	--	3,889	583,400	---	---	55.9		217,500	--	BC	
	b	2	M	CC	TP	120	2	14	17	257	72	1926	2,056	246,700	---	---	27.8		41,058	--	BC	
	c	2	M	CC	TP	100[4]	2	14	17	257	60	1923	1,548	154,800	---	---	72.3		67,150	--	BC	
	Plant					370					232			984,900	1,626	605		51.7	325,708	200		61.8
28	a	4	M	-	TP	330	3	17-3/4	22	225	220	1927	3,747-1/2	1,236,675	1,111	1,113	62.9	62.9	518,500	467	BC	43.0

NOTES:

* A - Air
M - Mechanical

** S - Separate
C.C. - Crank Case
(For 2 - Stroke Cycle Only

*** C.C. - Continuous Centrifuging
B.C. - Batch
S - Settling
C - Chemical

1 - Semi-Diesel.
2 - K.W. Rating Assumed; Name plate Ratings are 700 and 1,300.
3 - Includes 500 gallons Initial Filling.
4 - May 10, 1929.
5 - January, 1929.
6 - July, 1929.

The remarkable lubricating-oil economy obtained in the case of plant No. 45 deserves particular mention. When the committee questioned the figures, this operator was able to furnish written proof from his oil company as to the total amount of oil used and gave in addition a plausible explanation for the differences in economy as shown by the various units. Engines 45a and 45b are of trunk-piston construction, whereas engines 45c, 45d, and 45e are crosshead type. Engine 45c has two oil leads per cylinder, set 180 deg. apart, and is equipped with plain piston rings. Engines 45d and 45e have each four oil leads per cylinder, spaced 90 deg. apart, and are equipped with special patented piston rings.

Attendance. The questionnaire used this year called for the total cost of the attendance per period, the number of men per shift, and the number of shifts per day. The individual plants were asked for additional information relative to the cost of superintendence chargeable to the production cost, and this cost for superintendence is included in the attendance cost for every plant.

In next year's questionnaire this point will be brought out more clearly.

The greatest horsepower in charge of one man per shift is 3450, which obtains in the case of plant No. 91. The summary of attendance and superintendence cost is as follows:

Cost per net kw-hr.:	Mills
Arithmetical average of all plants	4.228
Weighted average of all plants	2.031

Table 2 - Information Covering Fuel Oil

Plant Number	Engine Designation	Engine Cycle	Injection System*	Scavenging System**	Rated B.H.P.	Number of Cylinders	Cylinder Bore - Inches	Stroke - Inches	Rated R.P.M.	Generator Rating - K.W.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Gross Output - K.W.Hrs.	Gallons of Fuel Oil Used	Gross K.W. Hrs. per Gallon of Fuel Oil	Running Engine Capacity Factor (See Text)	Running Plant Capacity Factor (See Text)	Nature of Fuel Oil Used***	Average Cost of Fuel Oil - Cents per Gallon	Is Fuel Centrifuged?	Plant Altitude Above Sea Level - Feet	Is Jacket Water Heat Utilized?	Is Exhaust Heat Utilized?
43	a	4	A	-	500	3	22	29-1/2	150	300	1915	735	163,576	16,752	9.76	74.2		38 sec. S.F. @ 770 F 1.0% S. Trace-Ash 0.1% W & S.		No		No	No
	b	4	A	-	500	3	22	29-1/2	150	300	1916	1,216	249,744	25,699	9.72	68.5				"		"	"
	c	4	A	-	520	4	19	24-1/2	200	350	1919	1,631-1/2	423,410	46,967	9.01	74.2				"		"	"
	d	4	A	-	520	4	19	24-1/2	200	350	1920	1,476-1/2	361,094	39,816	9.07	69.9			4.94	"		"	"
	e	4	A	-	1,000	6	20-1/2	36	150	700	1922	2,355-1/2	993,320	104,545	9.49	80.2		30.2 Sec. S.U. @ 100° F 1.04% S .023% Ash .03% W & S 13.6% asphaltum		"		"	"
	f	4	A	-	1,000	6	20-1/2	36	150	700	1925	1,760-1/2	785,040	82,036	9.57	63.7				"		"	"
	g	2	A	S	3,750	6	30	42	124	2,600	1928	7,302-1/2	13,500,800	1,152,232	11.72	71.2				"		"	"
	h	2	A	S	3,750	6	30	42	124	2,800	1929[1]	3,782-1/4	7,375,600[3]	562,034	13.12[3]	69.7			4.20	"		"	"
	Plant				11,540					6,100			23,852,584	2,030,081	11.74		69.9	1/2 hr. @ 4000 C	4.25		2,500		
46	a	2	A	S	1,250	5	20-3/4	26	180	850[3]	1922	5,938	4,034,500	394,476	10.22	80.0		18,800 B.T.U. 35 Sec. S.F. @ 122° F 0.75% S 0.3% W & S		No		Yes	No
	b	2	A	S	1,250	5	20-3/4	26	180	850[3]	1922	4,300	2,885,000	283,923	10.16	78.9				"		"	"
	c	2	A	S	2,200	4	28	44	120	1,500[3]	1922	7,651	9,671,200	798,137	12.10	84.3				"		"	"
	d	2	A	S	2,200	4	28	44	120	1,500[3]	1922	7,481	9,555,200	793,282	12.03	85.1				"		"	"
	Plant				6,900					4,700			26,145,900	2,269,818	11.52		83.3		4.92		5,000		
45	a	4	A	-	600	6	16-1/2	24	200	400	1923	1,286	276,000	27,293	10.11	53.7		39 Sec. S.U. @ 100° F 19,000 B.T.U. 0.35% S 0.5% W & S Nil - C.C.		No		No	Yes
	b	4	A	-	600	6	16-1/2	24	200	400	1923	1,265	280,550	28,250	9.93	55.4				"		"	"
	c	4	A	-	750	4	23	32	150	500	1923	2,451	828,850	80,289	10.32	67.6				"		"	"
	d	4	A	-	1,150	6	23	32	150	800	1926	5,575	3,325,250	291,135	11.41	74.5				"		"	"
	e	4	A	-	1,150	6	23	32	150	800	1926	5,468	3,334,750	288,965	11.53	76.2				"		"	"
	Plant				4,250					2,900			8,045,400	715,932	11.23		72.5		5.23		50		
2	a	4	A	-	1,150	6	23	29	166-2/3	800	1925	7,829-1/4	5,971,810	587,090	10.53	96.3		19,200 B.T.U. 0.56% S 0.62% C.C. 0.02% Ash. 0.15% W & S		No		No	Yes
	b	4	A	-	1,150	6	23	29	166-2/3	800	1925	7,500-1/4	5,628,380	540,508	10.42	93.8				"		"	"
	c	4	A	-	1,150	6	23	29	166-2/3	800	1925	6,859-3/4	5,152,810	488,202	10.54	93.9				"		"	"
	Plant				3,450					2,400			16,752,980	1,596,800	10.49		94.4		2.71		725		
91	a	4	M	-	1,125	6	22	30	180	800	1927	8,460	3,341,525	---	---	49.3				No		No	No
	b	4	M	-	1,125	6	22	30	180	800	1928	6,615	2,628,075	---	---	49.6				"		"	"
	c	4	M	-	600	6	17	24	225	400	1927	4,329	1,050,925	---	---	60.7				"		"	"
	d	4	M	-	600	6	17	24	225	400	1927	3,778	941,475	---	---	62.3				"		"	"
	Plant				3,450					2,400			7,962,000	723,568	11.00		52.0		3.90		6,000		
52	a	4	A	-	830	4	23	32	164	560	1928	762	292,400	27,517	10.62	68.5		19,100 B.T.U. 100 Sec. S.U. @ 77° F 1.2% S 1.0% W & S		No		No	Yes
	b	4	A	-	1,250	6	23	32	164	850	1928	4,589	2,576,900	246,475	10.46	66.5				"		"	"
	c	4	A	-	1,250	6	23	32	164	850	1928	5,441	2,958,600	278,524	10.62	63.9				"		"	"
	Plant				3,330					2,260			5,829,900	552,516	10.55		65.3		5.56		30		
3	a	4	M	-	400	6	14-1/2	18	277	275	1923	860	275,000	32,000	8.59	16.2		19,329 B.T.U. 60 Sec. S.U. @ 60° F 1.0% S Nil - W & S		No		No	No
	b	4	A	-	800	6	17	24	200	540	1924	0	0	0	---	---				"		"	"
	c	4	A	-	800	8	17	24	200	540	1926	2,190	640,000	73,495	8.71	54.1				"		"	"
	d	4	M	-	1,125	6	22	30	180	750	1927	7,008	1,900,000	202,200	9.40	36.2				"		"	"
	Plant				3,125					2,105			2,815,000	307,695	9.15		42.2		4.53		20		
92	a	2	A	S	1,250	5	20-3/4	26	180	900	1928	5,910	3,946,900	---	---	74.2				No		No	No
	b	2	A	S	1,250	5	20-3/4	26	180	900	1928	4,879	3,002,900	---	---	68.3				"		"	"
	Plant				2,500					1,800			6,949,800	676,526	10.27		71.6		2.15		2,580		
41	a	4	A	-	520	3	22	29-1/2	164	400	1922	---	---	---	---	---		18,963 B.T.U. 0.5% S 0.2% W & S		No		No	No
	b	4	A	-	700	4	22	29-1/2	164	500	1923	---	---	---	---	---				"		"	"
	c	4	A	-	1,150	6	23	29-1/2	164	900	1928	---	---	---	---	---				"		"	"
	Plant				2,370					1,800			3,820,810	374,180	10.21		---		5.51		20		
5	a	2	M	S	720	6	16	20	257	480	---	---	---	---	---	---				-		-	-
	b	2	M	S	720	6	16	20	257	480	---	---	---	---	---	---				-		-	-
	c	2	M	S	720	6	16	20	257	480	---	---	---	---	---	---				-		-	-
	Plant				2,160					1,440			406,230	42,911	9.46		---		4.15		---		
6	a	2	M	CC	300[4]	6	14	17	257	200	1926	---	---	---	---	---				-		-	-
	b	4	A	-	600	6	17	25	200	400	1926	---	---	---	---	---				-		-	-
	c	4	A	-	600	6	17	25	200	412	1927	---	---	---	---	---				-		-	-
	d	4	A	-	600	6	17	25	200	412	1928	---	---	---	---	---				-		-	-
	Plant				2,100					1,424			1,356,500	116,879	11.60		---		4.70		---		

Table 2 - Information Covering Fuel Oil

Plant Number	Engine Designation	Engine Cycle	Injection System	Scavenging System	Rated B.H.P.	Number of Cylinders	Cylinder Bore - Inches	Stroke - Inches	Rated R.P.M.	Generator Rating - K.W.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Gross Output - K.W.Hrs.	Gallons of Fuel Oil Used	Gross K.W. Hrs. per Gallon of Fuel Oil	Running Engine Capacity Factor (See Text)	Running Plant Capacity Factor (See Text)	Nature of Fuel Oil Used**	Average Cost of Fuel Oil - Cents per Gallon	Is Fuel Centrifuged?	Plant Altitude Above Sea Level - Feet	Is Jacket Water Heat Utilized?	Is Exhaust Heat Utilized?
93	a	2	M	S	560	4	16	20	257	376	1928	4,933	954,200	---	---	51.4				No		No	No
	b	2	M	S	700	5	16	20	257	480	1928	4,966	1,167,900	---	---	49.0				"		"	"
	c	2	M	S	700	5	16	20	257	480	1928	5,676	996,600	---	---	36.6				"		"	"
	Plant				1,960					1,336			3,118,700	358,259	8.71		44.8		4.16		15		
7	a	4	M	-	360	6	11-1/2	16	277	225	1925	3,587-1/2	543,000	---	---	67.3		19,500 B.T.U.		Yes		No	No
	b	4	M	-	360	6	11-1/2	16	277	225	1925	4,461	626,300	---	---	62.4		44.4 Sec. S.U. @ 100° F 0.23% S		"		"	"
	c	4	M	-	360	6	11-1/2	16	277	225	1925	4,597-1/2	682,000	---	---	65.9		0.016% C.C.		"		"	"
	d	4	M	-	750	6	16	22	257	500	1927	5,265-1/2	1,698,100	---	---	64.5		0.012% Ash		"		"	"
	Plant				1,830					1,175			3,549,400	296,499	11.96		64.8	1.3% W & S	5.77		1,230		
18	a	2	M	CC	450	5	15-1/4	16	275	300	1922	---	---	---	---	---				-		-	-
	b	4	A	-	600	6	17	25	200	410	1926	---	---	---	---	---				-		-	-
	c	4	A	-	600	6	17	25	200	410	1928	---	---	---	---	---				-		-	-
	Plant				1,650					1,120			2,448,290	225,513	10.86		---		4.71		---		
10	a	4	A	-	750	4	22	29	166-2/3	500	1924	1,558	614,700	54,887	11.19	78.9		19,200 B.T.U.		No		No	No
	b	2	A	S	750	4	17	27	176-1/2	500	1925	7,001	2,582,180	263,365	9.81	73.8		0.56% S 3.68% C.C. .02% Ash 0.15% W & S		"		"	"
	Plant				1,500					1,000			3,196,880	318,252	10.03		74.7		2.97		20		
11	a	4	A	-	750	4	22	29	166-2/3	500	1924	144-3/4	61,390	6,107	10.06	84.8		19,200 B.T.U.		No		No	Yes
	b	4	A	-	600	6	16-1/2	24	200	404	1926	2,560-3/4	1,013,600	88,139	11.50	98.0		0.56% S 3.68% C.C. 0.02% Ash		"		"	"
	Plant				1,350					904			1,074,990	94,246	11.40		97.1	0.15% W & S	2.38		132		
13	a	4	A	-	275	4	13-1/2	19-1/2	257	175	1923	6,052	655,200	67,480	9.71	61.9		18,750 B.T.U.		No		No	No
	b	4	A	-	200	3	13-1/2	19-1/2	257	125	1923	3,125	250,900	27,200	9.23	64.2		40 Sec. S.U. @ 100° F 0.28% S Negl. - W & S		"		"	"
	c	4	A	-	750	4	23	29-1/2	164	500	1925	1,870	427,400	50,450	8.47	45.7				"		"	"
	Plant				1,225					800			1,333,500	145,130	9.19		55.9		6.00		---		
94	a	4	A	-	600	6	17	24	200	410	1927	5,660	1,556,490	---	---	67.2				No		No	No
	b	4	A	-	600	6	17	24	200	410	1927	5,712	1,564,570	---	---	66.7				"		"	"
	Plant				1,200					820			3,123,060	266,304	11.71		67.0		3.17		1,000		
17	a	4	A	-	600	6	17	25	200	410	1926	---	---	---	---	---				-		-	-
	b	4	A	-	600	6	17	25	200	410	1926	---	---	---	---	---				-		-	-
	Plant				1,200					820			1,667,688	167,395	9.96		---		4.52		---		
68	a	2	M	CC	240	4	14	17	257	140	1926	4,460	301,673	33,444	9.02	48.1		0.5% S		No		No	No
	b	2	M	CC	360	6	14	17	257	250	1925	5,092	807,120	89,500	9.02	63.4				"		"	"
	c	2	M	S	560	4	16	20	257	375	1928	355	78,700	8,179	9.62	59.1				"		"	"
	Plant				1,160					765			1,187,493	131,123	9.06		58.4		4.49		632		
95	a	2	M	S	560	4	16	20	257	375	1929[5]	5,136	910,500	---	---	47.2				No		No	No
	b	2	M	S	560	4	16	20	257	375	1929[5]	4,994	912,600	---	---	48.7				"		"	"
	Plant				1,120					750			1,823,100	194,935	9.36		48.0		3.23		746		
96	a	4	M	-	600	6	17	24	225	400	1925	3,206	532,200	---	---	41.5				No		No	No
	b	4	M	-	300	3	17	24	225	200	1923	5,091	596,400	---	---	58.6				"		"	"
	c	2	M	CC	200[1]	4	14	17	257	136	1921	968	66,200	---	---	50.3				"		"	"
	Plant				1,100					736			1,194,800	135,067	8.86		49.1		3.61		606		
97	a	4	A	-	520	4	19	24	200	333	1915	5,383	---	---	---	---				No		No	No
	b	4	A	-	250	4	13-3/4	17-1/2	257	150	1914	7,530	---	---	---	---				"		"	"
	c	4	A	-	250	4	13-3/4	17-1/2	257	210	1914	5,638	---	---	---	---				"		"	"
	Plant				1,020					693			2,097,440	222,247	9.44		51.1		3.18		322		
98	a	2	M	CC	360	6	14	17	257	240	1926	6,342	923,400	---	---	60.6				No		No	No
	b	2	M	CC	360	6	14	17	257	240	1929[6]	2,564	419,400	---	---	68.2				"		"	"
	c	2	M	CC	180	3	14	17	257	120	1926	4,623	365,650	---	---	65.9				"		"	"
	d	2	M	CC	100[2]	2	14	17	257	65	---	1,527	57,460	---	---	57.9				"		"	"
	Plant				1,000					665			1,765,910	220,275	8.02		63.2		5.57		2,931		
100	a	2	M	CC	300[1]	6	14	17	257	200	1923	3,169	366,000	---	---	60.9				No		No	No
	b	2	M	CC	240	4	14	17	257	160	1924	5,346	472,700	---	---	55.3				"		"	"
	c	2	M	CC	200[1]	4	14	17	257	136	1924	5,274	482,100	---	---	64.4				"		"	"
	Plant				740					496			1,320,800	153,658	8.59		59.9		3.36		1,286		

Table 2 - Information Covering Fuel Oil

Plant Number	Engine Designation	Engine Cycle	Injection System*	Scavenging System**	Rated B.H.P.	Number of Cylinders	Cylinder Bore - Inches	Stroke - Inches	Rated R.P.M.	Generator Rating - K.W.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Gross Output - K.W.Hrs.	Gallons of Fuel Oil Used	Gross K.W. Hrs. per Gallon of Fuel Oil	Running Engine Capacity Factor (See Text)	Running Plant Capacity Factor (See Text)	Nature of Fuel Oil Used***	Average Cost of Fuel Oil - Cents per Gallon	Is Fuel Centrifuged?	Plant Altitude Above Sea Level - Feet	Is Jacket Water Heat Utilized?	Is Exhaust Heat Utilized?
87	a	2	M	CC	360	6	14	17	257	250	1925	3,030	506,800	60,673	9.83	78.8		19,300 B.T.U. 60 Sec. S.U. @ 1000 F 0.56% S		No		No	No
	b	2	M	CC	360	6	14	17	257	250	1925	2,877	571,000	57,370	9.95	79.4				•		•	•
	Plant				720					500			1,167,800	118,043	9.90		79.1		5.94		860		
19	a	2	M	CC	100[1]	2	14	17	257	60	---	---	---	---	---	---				-		-	-
	b	2	M	CC	240	4	12-1/2	13-1/4	325	160	1927	---	---	---	---	---				-		-	-
	c	2	M	CC	360	4	15-1/4	16	275	240	1927	---	---	---	---	---				-		-	-
	Plant				700					460			663,520	84,670	7.72		---		4.50		---		
99	a	4	A	-	400	4	17	24	200	275	1927	6,659	1,342,100	---	---	73.3				No		No	No
	b	2	M	CC	200[1]	4	14	17	257	160	---	448	46,800	---	---	65.3				•		•	•
	Plant				600					435			1,388,900	118,010	11.76		72.9		3.09		700		
106	a	4	A	-	600	6	17	25	200	410	1929[4]	---	767,710	76,555	10.02	---	---		4.66	-	---	-	-
101	a	2	M	CC	240	4	14	17	257	160	1926	5,118	466,940	---	---	57.0				No		No	No
	b	2	M	CC	150[2]	3	14	17	257	120	1919	2,972	145,040	---	---	40.7				•		•	•
	c	2	M	CC	150[2]	3	14	17	257	100	---	1,633	108,136	---	---	66.2				•		•	•
	Plant				540					380			720,116	90,818	7.93		53.7		3.56		992		
102	a	2	M	CC	240	4	14	17	257	160	1928	5,109	329,900	---	---	40.4				No		No	No
	b	2	M	CC	240	4	14	17	257	160	1928	5,069	318,800	---	---	39.3				•		•	•
	Plant				480					320			648,700	88,517	7.33		39.8		3.41		565		
104	a	2	M	CC	120	2	14	17	257	72	---	7,387	400,440	---	---	75.5				No		No	No
	b	2	M	CC	120	2	14	17	257	72	---	4,592	185,390	---	---	56.0				•		•	•
	c	2	M	CC	100[2]	2	14	17	257	60	---	7,383	281,980	---	---	63.6				•		•	•
	d	2	M	CC	75[1]	2	12	15	300	48	---	6,753	267,080	---	---	62.4				•		•	•
	Plant				415					252			1,134,890	154,711	7.34		69.7		4.63		15		
24	a	4	M	-	200	3	14-1/2	18	277	136	1925	5,110	325,900	---	---	46.9				No		No	No
	b	4	M	-	200	3	14-1/2	18	277	136	1925	5,110	297,900	---	---	42.9				•		•	•
	Plant				400					272			623,800	74,240	8.41		44.9		4.00		760		
105	a	2	M	CC	240	4	14	17	257	160	---	6,030	499,600	---	---	51.8				No		No	No
	b	2	M	CC	150[2]	3	14	17	257	100	---	5,782	322,680	---	---	55.8				•		•	•
	Plant				390					260			822,280	100,706	8.16		53.3		4.63		3,100		
108	a	2	M	CC	150[1]	3	14	17	257	100	---	3,889	217,500	---	---	55.9				No		No	No
	b	2	M	CC	120	2	14	17	257	72	1926	2,056	41,058	---	---	27.8				•		•	•
	c	2	M	CC	100[2]	2	14	17	257	60	1923	1,548	67,150	---	---	72.3				•		•	•
	Plant				370					232			325,708	50,758	6.42		51.7		3.20		1,560		
28	a	4	M	-	330	3	17-3/4	22	225	220	1927	3,747-1/2	518,500	54,018	9.60	62.9	62.9	19,500 B.T.U. 1.0% C.C. less than 2.0% S	4.39	No	50	No	No

NOTES

* A - Air
W - Mechanical

** C.C. - Crank Case
S - Separate
(For 2-Stroke Cycle Only)

*** B.T.U. - British Thermal Units per Pound
S.U. - Saybolt Universal
S.F. - Saybolt Furol
S. - Sulphur
C.C. - Conradson Carbon
W & S - Water and Sediment
F. - Fahrenheit

1 - Semi-Diesel
2 - K.W. Rating Assumed; Name Plate Ratings are 700 and 1,300
3 - No deduction made in Gross Output for power to drive motor for Scavenging Blower
4 - May 10, 1929
5 - January, 1929
6 - July, 1929

Table 3 - Information Covering Maintenance

Plant Number	Engine Designation	Engine Cycle	Injection System	Scavenging System	Number of Cylinders	Rated B.H.P.	Generator Rating - K.W.	Year Engine Started to Work	Peak Load During Reported Period - K.W.	B.M.E.P. at Rated H.P. - Lbs. per Sq. In.	B.M.E.P. at Peak Load (90% Generator Efficiency)	Running Engine Capacity Factor (See Text)	Running Plant Capacity Factor (See Text)	Piston Cooling (Air-Oil-Water)	Are Air Filters Used?	Average Liner Wear for Reported Period - Inches	Liner Wear per 1,000 hours Operation - Inches	Type Cooling System (See Text)	Cost of Regular Engine Upkeep - Total Dollars - Material - Extra labor	Cost of Repairs for Engine Accidents - Total Dollars - Material - Extra labor	Cost of Engine Betterments - Total Dollars - Material - Extra labor	Total Engine Repairs in Dollars per Horsepower per year.	Number of Enforced Shutdowns	Total Duration of Enforced Shutdowns - Hours	Number of Shifts per Day	Number of Attendants/Shift
43	a	4	A	-	3	500	300	1915	310	78.4	72.4	74.2		W	No	.002	.0027	B-E	352-1,996[9]	None	None	2.35[9]	-	-		
	b	4	A	-	3	500	300	1916	300	78.4	70.1	68.5		W	"	.001	.0008	"	"	"	"	"	-	-		
	c	4	A	-	4	520	350	1919	310	74.0	65.7	74.2		W	"	.003	.0016	"	"	"	"	"	-	-		
	d	4	A	-	4	520	350	1920	320	74.0	67.8	69.9		W	"	.004	.0027	"	428-834[9]	"	"	1.21[9]	-	-		
	e	4	A	-	6	1,000	700	1922	700	73.9	77.1	60.2		W	"	-	--	"	"	"	"	"	-	-		
	f	4	A	-	6	1,000	700	1925	700	73.9	77.1	63.7		W	"	-	--	"	2,019-1,813[9]	"	"	1.92[9]	-	-		
	g	2	A	S	6	3,750	2,600	1928	3,000	67.2	80.1	71.2		W	Yes	.070	.0096	"	7,320-3,869[9]	"	"	2.98[9]	-	-		
	h	2	A	S	6	3,750	2,800	1929[4]	3,100	67.2	82.8	69.7		W	"	.035	.0093	"	1,280-746[9]	"	"	0.86[9]	-	-		
	Plant					11,540	8,100		6,000				69.9												3	4
46	a	2	A	S	5	1,250	850[2]	1922	-	62.5	-	80.0		W	No	.012	.0020	B-E					-	-		
	b	2	A	S	5	1,250	850[2]	1922	-	62.5	-	78.9		W	"	-	--	"					-	-	1	5
	c	2	A	S	4	2,200	1,500[2]	1922	-	66.9	-	84.3		W	"	.008	.0011	"		33,129[7]		4.80[7]	-	-	and	
	d	2	A	S	4	2,200	1,500[2]	1922	--	66.9	-	85.1		W	"	-	--	"					-	-	2	3
	Plant					6,900	4,700		4,300				83.3													
45	a	4	A	-	6	600	400	1923	400	77.2	76.6	53.7		A	Yes	.004	.0031	B		None	None		0	-		
	b	4	A	-	6	600	400	1923	400	77.2	76.6	55.4		A	"	.004	.0032	"		"	"		0	-		
	c	4	A	-	4	750	500	1923	550	74.5	81.4	67.6		W	"	.006	.0024	"	1,516-4,902[9]	"	"	1.51[9]	0	-		
	d	4	A	-	6	1,150	800	1926	850	76.1	83.8	74.5		W	"	.006	.0011	"		"	"		1	3		
	e	4	A	-	6	1,150	800	1926	850	76.1	83.8	76.2		W	"	.006	.0011	"		"	"		1	2		
	Plant					4,250	2,900		2,500				72.5												3	2
2	a	4	A	-	6	1,150	800	1925	830	75.6	81.3	95.3		W	No	-	.0040	A					-	-	2	2
	b	4	A	-	6	1,150	800	1925	830	75.6	81.3	93.8		W	"	-	.0045	"		5,654[10]		1.64[10]	-	-	and	
	c	4	A	-	6	1,150	800	1925	830	75.6	81.3	93.9		W	"	-	.0045	"					-	-	1	6
	Plant					3,450	2,400		2,300				94.4													
91	a	4	M	-	6	1,125	800	1927	600[3]	72.3	57.4	49.3		A	Yes	-	--	D		None	None					
	b	4	M	-	6	1,125	800	1928	600[3]	72.3	57.4	49.6		A	"	-	--	"		"	"					
	c	4	M	-	6	600	400	1927	350[3]	64.6	56.2	60.7		A	"	-	--	"	1,637-None	"	"	0.47				
	d	4	M	-	6	600	400	1927	350[3]	64.6	56.2	62.3		A	"	-	--	"		"	"					
	Plant					3,450	2,400		1,950				52.0												3	1
52	a	4	A	-	4	830	560	1928	600	75.3	81.2	68.5		W	No	-	--	A					0	-		
	b	4	A	-	6	1,250	850	1928	880	75.7	79.4	68.5		W	"	-	--	"		Total 4,213[7]		1.27	2	84	2	2
	c	4	A	-	6	1,250	850	1928	885	75.7	79.9	63.9		W	"	-	--	"		"			1	2	and	
	Plant					3,330	2,260		2,140				65.3												1	3
3	a	4	M	-	6	400	275	1923	-	64.1		116.2		A	No	-	--	B	100-None	None	None	0.25	0	-		
	b	4	A	-	8	800	540	1924	-	72.7		-		A	"	-	--	"	None	"	"				2	2
	c	4	A	-	8	800	540	1926	400	72.7	54.2	54.1		A	"	.005	.0023	"	1,000-None	"	"	1.25	0	-	and	
	d	4	M	-	6	1,125	750	1927	600	72.3	57.4	36.2		A	Yes	.002	.0003	"	1,700-None	"	"	1.51	0	-	1	3
	Plant					3,125	2,105		1,000				42.2													
92	a	2	A	S	5	1,250	900	1928	900[3]	62.5	67.0	74.2		W	Yes	-	--	D	7,565-None	780-None	None	4.90	-	-		
	b	2	A	S	5	1,250	900	1928	900[3]	62.5	67.0	68.3		W	"	-	--	"		2,463-1,423	"		-	-		
	Plant					2,500	1,800		1,800				71.6												3	1
41	a	4	A	-	3	520	400	1922	420	74.6	89.7	-		W	No	-	--	A		None	None		-	-		
	b	4	A	-	4	700	500	1923	510	75.3	81.7	-		W	"	-	--	"	823-None	"	"	0.35	-	-		
	c	4	A	-	6	1,150	900	1928	900	75.5	88.0	-		W	"	-	--	"		"	"		-	-		
	Plant					2,370	1,800		1,100																3	2
5	a	2	M	S	6	720	480	-	-	46.0	-	-		O	-	-	--	B-E					-	-		
	b	2	M	S	6	720	480	-	-	46.0	-	-		O	-	-	--	"		4,606[9]		2.13[9]	-	-		
	c	2	M	S	6	720	480	-	-	46.0	-	-		O	-	-	--	"					-	-		
	Plant					2,160	1,440		1,250																	
6	a	2	M	CC	6	300[1]	200	1928	-	29.4	-	-	-	A	-	-	--	B-E					-	-		
	b	4	A	-	6	600	400	1928	-	69.8	-	-	-	A	-	-	--	"		1,499[9]		0.71[9]	-	-		
	c	4	A	-	6	600	412	1927	-	69.8	-	-	-	A	-	-	--	"					-	-		
	d	4	A	-	6	600	412	1928	-	69.8	-	-	-	A	-	-	--	"					-	-		
	Plant					2,100	1,424		1,550																	
93	a	2	M	S	4	560	376	1928	400[3]	53.6	57.0	51.4		O	Yes	.020	.0045	D			None		-	-		
	b	2	M	S	5	700	480	1928	500[3]	53.6	57.0	49.0		O	"	.025	.0050	"	503-None	569-None	"	0.55	-	-		
	c	2	M	S	5	700	480	1928	500[3]	53.6	57.0	36.6		O	"	.022	.0039	"			"		-	-		
	Plant					1,960	1,336		1,300				44.8												3	1

Table 3 - Information Covering Maintenance

Plant Number	Engine Designation	Engine Cycle	Injection System	Scavenging System	Number of Cylinders	Rated B.H.P.	Generator Rating - K.W.	Year Engine Started to Work	Peak Load During Reported Period - K.W.	B.M.E.P. at Rated H.P. - Lbs. per Sq. in.	B.H.P. at Peak Load (90% Generator Efficiency)	Running Engine Capacity Factor (See Text)	Running Plant Capacity Factor (See Text)	Piston Cooling (Air-Oil-Water)	Are Air Filters Used?	Average Liner Wear for Reported Period - Inches	Liner Wear per 1,000 hours Operation - Inches	Type Cooling System (See Text)	Cost of Regular Engine Upkeep - Total Dollars - Material - Extra Labor	Cost of Repairs for Engine Accidents - Total Dollars - Material - Extra labor	Cost of Engine Betterments - Total Dollars - Material - Extra labor	Total Engine Repairs in Dollars per Horsepower per year.	Number of Enforced Shutdowns	Total Duration of Enforced Shutdowns - Hours	Number of Shifts per Day	Number of Attendants/Shift
7	a	4	M	-	6	380	225	1925	225	103.2	96.0	67.3		A	Yes	-	--	D	5,586-2,949[8]	None	None	4.66[8]	-	-		
	b	4	M	-	6	360	225	1925	225	103.2	96.0	62.4		A	"	-	--	"		"	"		-	-		
	c	4	M	-	6	360	225	1925	225	103.2	96.0	65.9		A	"	-	--	"		"	"		-	-		
	d	4	M	-	6	750	500	1927	450	87.1	77.9	64.5		A	"	-	--	"		"	"		-	-		
	Plant					1,830	1,175		1,125				64.8												3	2
18	a	2	M	CC	5	450	300	1922	--	44.3	-	-		A	-	-	--	B-E					-	-		
	b	4	A	-	6	600	410	1926	--	69.8	-	-		A	-	-	--	B-E		4,521'		2.74'	-	-		
	c	4	A	-	6	600	410	1928	--	69.8	-	-		A	-	-	--	B-E					-	-		
	Plant					1,650	1,120		1,060				-												-	-
10	a	4	A	-	4	750	500	1924	400	80.8	64.2	78.9		W	No	-	.0045	A		Total-327"		0.44"	-	-	2	2
	b	2	A	S	4	750	500	1925	400	68.5	54.4	73.8		W	Yes	-	.0180	"		Total-528"		0.70"	-	-	and	
	Plant					1,500	1,000		400				74.7												1	4
11	a	4	A	-	4	750	500	1924	500	80.8	80.3	84.8		W	No	-	--	A		Total-3"		Nil	-	-	2	2
	b	4	A	-	6	600	404	1926	400	77.1	76.6	98.0		W	"	-	.0045	"		Total-656"		1.09"	-	-	and	
	Plant					1,350	904		500				97.1												1	4
13	a	4	A	-	4	275	175	1923	185	75.8	75.8	61.9		A	No	.006	.0010	A	514-None	None	None	1.87	0	-		
	b	4	A	-	3	200	125	1923	135	73.5	73.8	64.2		A	"	.005	.0016	"	165- "	"	"	0.83	0	-		
	c	4	A	-	4	750	500	1925	450	73.8	65.9	45.7		W	"	.005	.0027	"	359- "	"	"	0.48	0	-		
	Plant					1,225	800		450				55.9												3	1
94	a	4	A	-	6	600	410	1927	460[9]	72.7	83.0	67.2		A	Yes	-	--	D	581-None	170-None	None	0.63	-	-		
	b	4	A	-	6	600	410	1927	530[9]	72.7	95.7	66.7		A	Yes	-	--	"			"		-	-		
	Plant					1,200	820		900				67.0												3	1
17	a	4	A	-	6	600	410	1926	-	69.8	-	-		A	-	-	--	B-E					-	-		
	b	4	A	-	6	600	410	1926	-	69.8	-	-		A	-	-	--	B-E		2,323'		1.94'	-	-		
	Plant					1,200	820		920				-												-	-
68	a	2	M	CC	4	240	140	1925	130	35.3	28.5	48.1		A	No	-	--	B		None	None		1	‡		
	b	2	M	CC	6	360	250	1925	230	35.3	33.6	63.4		A	"	-	--	B	511'	550	"	0.92'	1	‡		
	c	2	M	S	4	560	375	1928	410	53.6	58.4	59.1		O	Yes	-	--	B		None	"		0	-		
	Plant					1,160	765		390				58.4												3	1
95	a	2	M	S	4	560	375	1929'	400[9]	53.6	57.0	47.2		O	Yes	.0295	.0058	B	599-None	None	None	0.54	-	-		
	b	2	M	S	4	560	375	1929'	400[9]	53.6	57.0	48.7		O	"	.036	.0072	"		"	"		-	-		
	Plant					1,120	750		800				48.0												3	1
96	a	4	M	-	6	600	400	1925	400[9]	64.6	64.0	41.6		A	No	-	--	A	167-None	None	None	0.28	-	-		
	b	4	M	-	3	300	200	1923	200[9]	64.6	64.0	58.6		A	"	-	--	A	461-None	3,519-480	"	14.85	-	-		
	c	2	M	CC	4	200[4]	138	1921	200[9]	29.4	43.8	50.3		A	"	-	--	A	343-None	None	"	1.72	-	-		
	Plant					1,100	736		800				49.1												3	1
97	a	4	A	-	4	520	333	1915	320	75.6	69.3	-		W	No	-	--	B		885-None	None		-	-		
	b	4	A	-	4	250	150	1914	140	74.1	61.8	-		A	"	-	--	B	759-None	514-None	"	3.09	-	-		
	c	4	A	-	4	250	210	1914	140	74.1	61.8	-		A	"	-	--	B		997-None	"		-	-		
	Plant					1,020	693		600				51.1												3	1
98	a	2	M	CC	6	360	240	1926	275[9]	35.3	40.1	60.6		A	Yes	-	--	D			None		-	-		
	b	2	M	CC	6	360	240	1929'	250[9]	35.3	36.5	68.2		A	"	-	--	D			"		-	-		
	c	2	M	CC	3	180	120	1926	150[9]	35.3	43.8	65.9		A	"	-	--	D	723-None	1,645-460	"	2.83	-	-		
	d	2	M	CC	2	100[3]	65	-	80[9]	29.4	35.1	57.9		A	No	-	--	D			"		-	-		
	Plant					1,000	665		575				63.2												3	1
100	a	2	M	CC	6	300[4]	200	1923	200[9]	29.4	29.2	60.9		A	Yes	-	--	B		None	None		-	-		
	b	2	M	CC	4	240	160	1924	100[9]	35.3	21.8	55.3		A	"	-	--	B	455-None	"	"	0.62	-	-		
	c	2	M	CC	4	200[4]	136	1924	100[9]	29.4	21.8	64.4		A	"	-	--	B		"	"		-	-		
	Plant					740	496		300				59.9												3	1
67	a	2	M	CC	6	360	250	1925	210	35.3	30.7	78.8		A	No	-	--	A	29-None	None	None	.08	2	2	1	2
	b	2	M	CC	6	360	250	1925	210	35.3	30.7	79.4		A	"	-	--	A	13-None	"	"	.04	2	4	1	1
	Plant					720	500		210				79.1													

Table 3 - Information Covering Maintenance

Plant Number	Engine Designation	Engine Cycle	Injection System*	Scavenging System**	Number of Cylinders	Rated B.H.P.	Generator Rating - K.W.	Year Engine Started to Work	Peak Load During Reported Period - K.W.	B.M.E.P. at Rated H.P. - Lbs. per Sq. In.	B.M.E.P. at Peak Load (90% Generator Efficiency)	Running Engine Capacity Factor (See Text)	Running Plant Capacity Factor (See Text)	Piston Cooling (Air-Oil-Water)	Are Air Filters Used?	Average Liner Wear for Reported Period - Inches	Liner Wear per 1,000 hours Operation - Inches	Type Cooling System (See Text)	Cost of Regular Engine Upkeep - Total Dollars - Material - Extra Labor	Cost of Repairs for Engine Accidents - Total Dollars - Material - Extra labor	Cost of Engine Betterments - Total Dollars - Material - Extra labor	Total Engine Repairs in Dollars per Horsepower per year.	Number of Enforced Shutdowns	Total Duration of Enforced Shutdowns - Hours	Number of Shifts per Day	Number of Attendants/Shift
19	a	2	M	CC	2	100'	60	-	-	29.4	-	-		A	-	-	--	B-E					-	-	-	-
	b	2	M	CC	4	240	160	1927	-	45.0	-	-		A	-	-	--	B-E		706'		1.01	-	-	-	-
	c	2	M	CC	4	360	240	1927	-	44.3	-	-		A	-	-	--	B-E					-	-	-	-
	Plant					700	460		250				-												-	-
99	a	4	A	-	4	400	275	1927	350'	72.7	94.8	73.3		A	Yes	-	--	B	304-None	428-None	None	1.83	-	-		
	b	2	M	CC	4	200'	160	-	150'	29.4	32.9	65.3		A	No	-	--	B	83-None	None	"	0.42	-	-		
	Plant					600	435		500				72.9												2	1
106	a	4	A	-	6	600	410	1929[4]	500	69.8	86.6	-	-	A	-	-	--	-		1508'		2.51[9]	-	-	-	-
101	a	2	M	CC	4	240	160	1926	150'	35.3	32.9	57.0		A	Yes	-	--	B			None		-	-		
	b	2	M	CC	3	150'	120	1919	90'	29.4	26.3	40.7		A	No	-	--	B	1,278-None	505-None	"	3.30	-	-		
	c	2	M	CC	3	150'	100	-	90'	29.4	26.3	66.2		A	No	-	--	B			"		-	-		
	Plant					540	360		225				53.7												3	1
102	a	2	M	CC	4	240	160	1928	100	35.3	21.9	40.4		A	Yes	-	--	D	206-None	117-None	None	0.67	-	-		
	b	2	M	CC	4	240	160	1928	200	35.3	43.8	39.3		A	"	-	--	D		None	"		-	-		
	Plant					480	320		300				39.8												3	1
104	a	2	M	CC	2	120	72	-	90'	35.3	39.4	75.5		A	No	-	--	B-E			None		-	-		
	b	2	M	CC	2	120	72	-	70'	35.3	30.7	56.0		A	"	-	--	B-E			"		-	-		
	c	2	M	CC	2	100'	60	-	60'	29.4	26.3	63.6		A	"	-	--	B-E	1,199-None	998-500	"	6.50	-	-		
	d	2	M	CC	2	75'	48	-	70'	29.1	40.5	82.4		A	"	-	--	B-E			"		-	-		
	Plant					415	252		260				69.7												3	1
24	a	4	M	-	3	200	136	1925	125	64.1	59.7	46.9		A	No	-	--	B-E	168-None	None	None	3.36	-	-		
	b	4	M	-	3	200	136	1925	125	64.1	59.7	42.9		A	"	-	--	"		1,002-175	"		-	-		
	Plant					400	272		158				44.9												3	1
103	a	2	M	CC	4	240	160	-	150	35.3	32.9	51.8		A	No	-	--	D	656-None	None	None	1.68	-	-		
	b	2	M	CC	3	150'	100	-	110	29.4	32.1	55.8		A	"	-	--	D		"	"		-	-		
	Plant					390	260		230				53.3												3	1
105	a	2	M	CC	3	150'	100	-	100'	29.4	29.2	55.9		A	Yes	-	--	B		None			-	-		
	b	2	M	CC	2	120	72	1926	70'	35.3	30.7	27.8		A	"	-	--	B	514-None	"	921-360	5.82	-	-		
	c	2	M	CC	2	100'	60	1923	60'	29.4	26.3	72.3		A	"	-	--	B		"			-	-		
	Plant					370	232		130				51.7												3	1
26	a	4	M	-	3	330	220	1927	300	71.1	96.3	62.9	62.9	A	No	-	--	A	479-295[9]	None	None	1.56[9]	0	-	1	1

NOTES:

* A - Air
M - Mechanical

** C.C. - Crank Case
S - Separate
(For 2-Stroke Cycle Only)

1 - Semi-Diesel.
2 - K.W. Ratings Assumed; Name Plate Ratings are 700 and 1,300.
3 - 60 Minute Peak.
4 - May 10, 1929.
5 - January, 1929.
6 - July, 1929.
7 - Labor and Material.
8 - Includes all Repairs to Electrical Equipment, Auxiliaries and Building.
9 - Includes all Supplies, and Repairs to Electrical Equipment, Auxiliaries and Building.
10 - Includes all Repairs to Electrical Equipment, Auxiliaries, but Not Building.

Table 4 - Information on Power Cost

Plant Number	Number of Engines	Total Installed B.H.P.	Total Installed K.W.	Total Plant Hours Operated in Reported Period	Number of Months in Reported Period	Total Gross Output- K.W.Hrs.	Total Net Output- K.W.Hrs.	Percent of Gross K.W.Hrs. for Plant Purposes	Annual Plant Load Factor (See Text)	Running Plant Capacity Factor (See Text)	Plant Service Factor (See Text)	Average Cost of Fuel Oil- Cents per gallon	Average Cost of Lubricating Oil- Cents per gallon	Costs per Net K.W.Hr. - Mills: Fuel Cost	Lubricating Oil Cost	Attendance Cost, including Superintendence	Cost of Water	Cost of Water Treatment	Cost of Miscellaneous Supplies	Cost of Engine Repairs	Cost of all Other Plant Repairs	Total Production Cost
43	8	11,540	8,100	8,760	12	23,852,584	22,591,027	5.4	45.4	69.9	48.1	4.25	53.5	3.818	.686	.601	0	.125	[3]	.914		6.144
46	4	6,900	4,700	8,760	12	26,145,900	24,909,500	4.6	69.4	83.3	76.3	4.92	37.9	4.484	.193	.826	.110	0	.213	1.329	.220	7.375
45	5	4,250	2,900	8,760	12	8,045,400	7,442,350	7.4	36.8	72.5	43.6	5.23	46.0	5.035	.092	1.652	0	0	.058	.863		7.700[1]
2	3	3,450	2,400	8,760	12	16,752,980	16,479,500	1.6	83.2	94.4	84.5	2.71	39.3	2.621	.333	1.402	0	0	.129	.343[3]		4.828[2]
91	4	3,450	2,400	8,616	12	7,962,000	7,585,725	4.7	46.6	52.0	72.8	3.90	71.4	3.723	.482	1.178	0	0	.157	.216	.067	5.823
52	3	3,330	2,260	8,760	12	5,829,900	5,722,032	1.8	31.1	65.3	45.2	5.58	85.5	5.384	.549	3.829	.525	0	.351	.736	.399	11.773[1]
3	4	3,125	2,105	8,760	12	2,815,000	2,341,730	16.8	32.1	42.2	36.2	4.53	49.6	5.953	.544	5.615	.416	0	.056	1.196	.149	13.929
92	2	2,500	1,800	8,760	12	6,949,800	6,662,389	4.2	44.1	71.6	61.6	2.15	60.5	2.199	.551	1.244	0	0	.167	1.850	.117	6.128
41	3	2,370	1,800	8,760	12	3,820,810	3,798,810	0.6	39.6	-	-	5.51	62.5	5.426	.477	4.108	0	0	.236	.217	.071	10.535
5	3	2,160	1,440	-	12	406,230	319,120	21.5	3.7	-	-	4.15	49.4	5.447	1.768	11.613	.336	3.220		14.430		36.814
6	4	2,100	1,424	-	12	1,356,500	1,318,898	2.8	10.0	-	-	4.70	53.6	4.167	.715	2.672	.215	.256		1.137		9.162
93	3	1,960	1,336	8,736	12	3,118,700	2,838,950	9.0	27.4	44.8	59.4	4.16	54.0	5.250	.518	2.495	0	0	.147	.378	.089	8.877
7	4	1,830	1,175	8,760	12	3,549,400	3,231,938	9.0	36.0	64.8	53.2	5.77	48.0	5.308	.356	3.058[1]	.724	0	.616	2.641		12.703[1]
18	3	1,650	1,120	-	12	2,448,290	2,351,123	4.0	26.4	-	-	4.71	51.1	4.517	.414	2.581	.125	.251		1.922		9.810
10	2	1,500	1,000	8,559	12	3,196,880	3,154,085	1.3	91.2	74.7	48.9	2.97	61.7	2.995	.965	3.278	0	0	.185	.271[3]		7.694[2]
11	2	1,350	904	2,705	12	1,074,990	1,061,460	1.3	24.5	97.1	14.0	2.38	44.6	2.116	.636	4.358	0	0	.220	.620[3]		7.950[2]
13	3	1,225	800	8,760	12	1,333,500	1,169,971	12.3	33.8	55.9	34.1	6.00	40.0	7.442	.572	4.744	0	0	1.004	.887	.765	15.414
94	2	1,200	820	8,760	12	3,123,060	2,982,340	4.5	39.6	67.0	64.9	3.17	47.7	2.830	.552	1.925	0	0	.360	.252	.190	6.109
17	2	1,200	820	-	12	1,667,688	1,611,876	3.4	20.7	-	-	4.52	57.8	4.691	.526	2.636	.159	.508		1.442		9.962
68	3	1,160	765	8,760	12	1,187,493	1,175,503	1.0	34.8	58.4	30.3	4.49	52.9	5.008	1.028	4.390	.092	0	[3]	.903		11.421
95	2	1,120	750	8,568	12	1,823,100	1,675,810	8.1	26.0	48.0	57.8	3.23	45.0	3.764	.319	3.600	0	0	.322	.358	.150	8.513
96	3	1,100	736	8,760	12	1,194,800	1,133,027	5.2	17.0	49.1	37.7	3.61	50.3	4.300	.986	3.865	0	0	.540	4.386	.186	14.263
97	3	1,020	693	8,736	12	2,097,440	2,027,967	3.3	39.9	51.1	67.7	3.18	50.4	3.483	1.513	3.006	0	0	.298	1.557	.099	9.956
98	4	1,000	665	8,520	12	1,765,910	1,677,817	5.0	35.1	63.2	47.9	5.57	50.4	7.305	1.048	3.053	0	0	.445	1.684	.212	13.747
100	3	740	496	8,832	12+	1,320,800	1,247,150	5.6	49.7	59.9	50.2	3.36	42.8	4.142	.729	4.688	0	0	.411	.365	.196	10.531
67	2	720	500	5,907	12	1,167,800	1,163,600	0.4	64.0	79.1	33.7	5.94	62.8	6.027	.549	1.602	.082	0	.129	.035	0	8.426
19	3	700	460	-	12	653,520	603,260	7.7	29.8	-	-	4.50	54.4	6.315	1.404	5.400	.245	.823		1.169		15.356
99	2	600	435	6,900	12	1,388,900	1,356,689	2.3	31.7	72.9	49.9	3.09	45.3	2.683	.413	3.038	0	0	.415	.600	.210	7.359
106	1	600	410	-	12	767,710	750,419	2.3	17.5	-	-	4.66	52.2	4.754	.656	2.657	.052	.558		2.011		10.688
101	3	540	380	8,736	12	720,116	666,871	7.4	36.5	53.7	40.3	3.56	51.9	4.852	1.428	6.386	0	0	.833	2.674	.565	16.738
102	2	480	320	8,760	12	648,700	577,920	10.9	24.7	39.8	58.1	3.41	46.0	5.217	1.607	8.514	0	0	.571	.559	.300	16.768
104	4	415	252	8,760	12	1,134,890	1,036,481	8.7	49.8	69.7	73.7	4.63	54.0	6.910	1.640	4.574	0	0	.370	2.601	.278	16.373
24	2	400	272	8,760	12	623,800	563,300	9.7	45.9	44.9	58.4	4.00	43.0	5.270	1.007	12.135	.563	.426	.107	2.388	.071	21.967
103	2	390	260	8,520	12	822,280	772,985	6.0	40.8	53.3	67.8	4.63	54.0	6.037	.990	5.818	0	0	.564	.848	.284	14.541
105	3	370	232	7,560	10+	325,708	272,138	16.4	33.1	51.7	35.9	3.20	61.8	5.968	3.688	14.600	0	0	1.763	6.593	.896	33.508
26	1	330	220	3,748	18	518,500	492,600	5.0	13.2	62.9	62.9	4.39	43.0	4.815	.969	5.077	0	0	.046	1.670		12.477
Totals: 107		68,775	47,650			141,611,979	134,766,761															
Weighted Averages:								4.8				4.18	51.5	4.139	.516	2.031	.079			1.370[4]		8.135
Arithmetical Averages: 3		1,910	1,324			3,933,666	3,743,521	6.1	37.0			4.19	52.1	4.729	.858	4.228	.101			2.343[4]		12.259

Notes:
1 - Includes Management
2 - Building Repairs not Included
3 - Supplies Included in Repairs
4 - Includes Cost of Water Treatment, Supplies and Repairs

Lowest cost per net kw-hr.:	Mills
Plants containing 2000 b.hp. and over:	
Plant No. 43	0.601
Plants containing 1000 to 2000 total b.hp.:	
Plant No. 94	1.925
Plants of less than 1000 total b.hp.:	
Plant No. 67	1.602

Supplies and Repairs. A total of 34 plants presented data which allowed segregation of the total supplies from the total repairs. For these 34 plants the supplies totaled 23 per cent of the supplies plus repairs, and the repairs totaled 77 per cent. There were 28 plants that fully segregated their costs under supplies, and it is found from these totals that the cost of water accounted for 27.5 per cent of the total supplies, the cost of water treatment for 0.7 per cent, and the cost of miscellaneous supplies for 71.8 per cent. There were 20 plants that furnished figures in which the repairs were completely segregated. For these 20 plants the cost of repairs on account of regular upkeep amounted to 47.4 per cent, the cost of repairs on account of accidents to 36.5 per cent, the cost of betterments to 2.7 per cent, and the cost of repairs to auxiliaries, electrical equipment, and buildings to 13.4 per cent of the total repairs.

If it is assumed that the various ratios outlined in the foregoing apply to the entire list of 36 plants, the weighted average costs of supplies and repairs, or 1.449 mills per net kw-hr., can be considered as made up from the following items:

	Mills
Cost of water	0.092
Cost of water treatment	0.002
Cost of miscellaneous supplies	0.239
Cost of regular upkeep repairs	0.529
Cost of accident repairs	0.407
Cost of betterments	0.031
Cost of repairs to auxiliaries, electrical equipment, and buildings	0.149

Inasmuch as these segregations have been arrived at by totaling actual costs, they are applicable only to weighted averages.

A summary of supply and repair costs follows. These costs represent the total of the cost of water and the cost of other supplies and repairs.

Cost per net kw-hr.:	Mills
Arithmetical average all plants	2.444
Weighted average all plants	1.449

Lowest repair and supply cost:	Mills
Plants of 2000 total b.hp. and over:	
Plant No. 2	0.472
Plants of 1000 to 2000 total b.hp.:	
Plant No. 10	0.456
Plants of less than 1000 total b.hp.:	
Plant No. 67	0.246

This year's questionnaire provided no space for listing repairs to plant auxiliaries, electrical equipment, and building. All of the plants listed, however, were requested to supply this information, and the total repairs in Table 4 include repairs to plant auxiliaries, electrical equipment, and buildings. Questionnaires to be sent out in the future will specifically require this information.

The various water-cooling systems are indicated by the following symbols:

System A, raw water going to waste after one pass
System B, raw water recirculated after passing over cooling tower or spray pond
System C, soft water continuously recirculated, cooled by raw water going to waste after one pass through heat exchanger
System D, soft water continuously recirculated, cooled by raw water also recirculated after cooling by cooling tower or spray pond
System E, any of the foregoing systems with engine circulating water treated.

Total Production Costs. The figures on total production costs can be summarized as follows:

Cost per net kw-hr.:	Mills
Arithmetical average of all plants	12.259
Weighted average of all plants	8.135

Lowest production cost per net kw-hr.:	Mills
Plants of 2000 total b.hp. and over:	
Plant No. 2	4.828
Plants of 1000 to 2000 total b.hp.:	
Plant No. 94	6.109
Plants of less than 1000 total b.hp.:	
Plant No. 99	7.359

Fixed charges. The following list contains the information received covering fixed charges:

Annual plant load factor, per cent (to nearest 5 per cent)	Percentages allowed for: Depreciation	Interest	Insurance-Tax	Misc.	Cost per net kw-hr., mills
Plants of 2000 total b.hp. and over					
85	4.0	4.5	1.0	0	2.078
35	3.41	5.02	0.32	1.56	7.800
30	5.0	4.15	0	0	6.435
Plants of 1000 to 2000 total b.hp.					
35	5.0	5.5	0	0	2.324
90	4.0	4.5	1.0	0	4.446
25	4.0	4.5	1.0	0	12.145
35	..	..	0	0	8.280
35	10.0[a] 5.0[b]	0	0	0	5.625
Plants of less than 1000 total b.hp.					
45	5.0	4.75	0.05	0	....
15	6.67	0	0	0	6.353

[a] Equipment. [b] Building.

The committee wishes to take this opportunity to thank the various oil-engine owners and operators who cooperated with it in this study. The data furnished were generally of a high degree of accuracy, and full credit is due to those who devoted time and effort to collect and supply this information.

Discussion

H. C. Thuerk.[2] The report submitted this year represents a very fine piece of work and includes a great deal of detailed information. The percentage of complete questionnaires received is relatively high and indicates that the committee is receiving cooperation from many Diesel-plant operators.

The data are well summarized, although the writer questions very seriously the advisability of stating weighted averages, as such values do not convey a correct picture of actual results. This is evident when it is realized that the output of three of the plants represents 47.3 per cent of the total output of the 36 plants included in the summary in Table 4. These three plants also operate at comparatively high load factors. Just what does this weighted average mean and of what value is it in connection with this cost investigation?

In this connection it should be pointed out that, under "Summary on Lubricating Oil Consumption," there is given a weighted average of 2,242 rated hp-hr. per gal. of lubricating oil. There are 21 of the 29 plants that have lubricating-oil consumption in excess of this quantity. The median value of lubricating-oil

[2] The J. G. White Management Corp., New York City. Assoc. Mem. A.S.M.E.

consumption for the 29 plants is 1669 rated hp-hr. per gal., or 814 gross kw-hr. per gal.

Under "Attendance Labor" a weighted average is given of 2.031 mills per kw-hr.; yet 28 plants out of the 36 have values higher than this. The median value for the 36 plants is 3.44 mills per kw-hr. In this connection it is interesting to note that this value checks very closely with the median value of 3.84 mills per kw-hr. for 22 plants listed in the 1929 report of the General Power Committee of the N.E.L.A.

Under "Total Production Cost" a weighted average is given of 8.135 mills per kw-hr. There are 26 of the 36 plants that have total production costs in excess of this value. The median value for these plants is 10.534 mills per kw-hr.

In several instances reference is made to the lowest or best results obtained for the various items. Since it is the objective of the Cost Committee to present a broad summary of these results, would it not be advisable to state the high and low limit of each of these items?

Since maintenance costs are based on the net output of the plants, would it not be more consistent to express fuel-oil and lubricating-oil consumptions on the same basis? In this connection it might be of interest to know that the statistics reported by the National Electric Light Association on power-plant generation are all based on the net output.

It is difficult to make use of the data given on "Fixed Charges" because the plants listed there are not identified with the plants listed in Table 4. It would also be of considerable value to know the total investment in each of these plants. Would it not be advisable to include this investment item on the questionnaire used to record the data for 1930?

It is also of help in using data such as are contained in this report, if it is known just what use is being made of the plant. In other words, it would be desirable to classify the plants so as to show whether they are municipal plants, private utility plants, or industrial plants. The General Power Committee of N.E.L.A. has reached this same conclusion and will use such a classification in its next year's report.

From the information given under "Fixed Charges" it is apparent that practically all of these plants are municipally owned. It would be of interest to know why two of the plants report no interest charges on their investment.

In comparing this year's report with the report submitted by the committee in 1929, it is noted that 14 of the 27 plants in the 1929 report are not included in the 1930 report. It is unfortunate that it was not possible to obtain another year's record on these 14 plants.

If the data on these 14 plants of the 1929 report are included with the data on the 36 plants recorded in this year's report, the following median values are obtained:

	Mills per kw-hr.
Fuel oil	4.85
Lubricating oil	0.625
Attendance labor	3.829
Maintenance	1.137
Supplies	0.430
Total operating cost	10.871
Median of totals	12.125

The 1930 report includes another year's data on 13 plants listed in the 1929 report. It would add materially to the value of the present report if a table had been included giving the operating results of these 13 plants over the two-year period. The writer would like to suggest that, in subsequent reports, two tables be published, one giving the current year's operating data and the other giving the accumulative data for as many years as possible. The latter table would give a much better picture of average costs to be obtained in a Diesel power plant, as it is well known that many of the items of cost, particularly the maintenance cost, do not reach stable values until several years after the plant has been placed in operation.

In the 1930 report the arithmetical average of the total operating costs for the 13 plants reported in both reports shows an increase of 6.2 per cent over the same value in the 1929 report.

E. W. Hammond.[3] This excellent report, prepared only with the greatest of effort, is of special value in the study of operating costs for Diesel plants. The report does deal slightly on fixed charges which need consideration when calculating the total cost of producing power. Since there is no common bases established for figuring these charges, nor does the cost of equipment remain fixed over a period of years, the committee has wisely refrained from dealing at length on this item. When fixed charges are to be considered, it is necessary to show the detail of the individual charges made, preferably expressed in percentage figures, as well as totals, and the cost of the plant, segregating equipment and plant buildings so that comparison of one plant can easily be made with another plant on a common base. In the plant installed in 1915 the Diesel cost was approximately $120 per hp. as against a cost of $60 per hp. for the Diesel installed in 1929. It is obviously unfair, therefore, when considering fixed charges, to compare the exact size of plant installed in 1915 with that of a plant installed in 1929 without making proper correction for the difference in costs of plants. It would seem inadvisable, therefore, to attempt to include any data on fixed charges in the next report, as a questionnaire to obtain this data completely would necessarily be lengthy, and the real value of the report is to show actual operating performance. Fixed charges for any new plant are easily computed where required.

We hope this report will continue to be an annual paper covering the operating cost of Diesel plants, for the data are invaluable to both the user and the manufacturer of Diesels.

Edgar J. Kates.[4] This is an exceedingly creditable report and compares favorably with previous reports on oil-engine power costs compiled by the A.S.M.E. and other organizations. The report discloses, for each plant, many more items of information than usual, and this greatly facilitates making cost comparisons between some specific plant in the report and some other plant in which the reader is interested, whether it be already in operation or merely in prospect.

It seems that for the present, and for some time to come, this sort of comparison will be the most useful application of such reports. In other words, when one desires to judge the performance of an existing oil-engine power plant or to estimate the operating cost of a projected plant, he will locate in the report several plants of approximately the same size, the same load factor, and the same operating conditions as the one in which he is interested, and from these similar plants he will select for his standard of performance the one which shows the best results.

In the case of fuel and lubricating oil such specific comparisons can readily be made, inasmuch as the report includes the cost per gallon of these commodities, thus enabling adjustment to be made for different prices. When one knows the kilowatt-hours per gallon of fuel and the rated horsepower-hours per gallon of lubricating oil, it is easy to compute the fuel and lubricating costs for whatever unit prices may apply.

Likewise the usefulness of the report would have been increased if, also, some attempt had been made to report attendance cost on a unit basis. Wage scales vary widely, and some such figures as

[3] Sales Division, Buffalo Works, Worthington Pump and Machinery Corporation, Buffalo, N. Y.

[4] Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

"average wage per hour" or "rated horsepower-hours per man-hour" would have facilitated comparisons.

As for maintenance costs, it is well understood that for any one engine the maintenance cost varies considerably from year to year, and consequently it is necessary to obtain the maintenance cost over a period of at least five years to obtain a fair average. It is presumably the intention of the committee, when compiling future reports, to include maintenance costs for previous years so that trustworthy averages will finally result.

Attempts have been made to draw conclusions from this and similar reports as to the *average* cost of operating different types of oil engines. Such attempts are, however, quite unsound because of the small number of plants included in the report and the vital influence of variations in load factor and in the price of fuel, lubricating oil, and attendance. Averages computed on the basis of the amount of data now available may be worse than meaningless—they may be quite misleading. When a great deal more data shall have come to hand, some worth-while conclusions based on averages will be possible through careful selection, but at the present time averages mean less than nothing.

A. E. Flowers.[5] The committee is to be congratulated upon the large amount of data obtained and the very complete tabulation already made and presented in such manner that it may be subjected to further analysis whenever desirable.

It is noted that considerable information is given in regard to the characteristics of the fuel oil used, which will be very useful to the Research and Standardization Committees on Diesel Fuel Oil.

There is given complete information in regard to the engine and lubricating oil consumption and its cost, but no information at all in regard to the characteristics of the lubricating oil. If it is possible to do so, the present information should be supplemented by data upon the viscosity, carbon residue, and sulphur in the lubricating oil and the symbols used for describing, in the tabulation, the method for lubricating-oil treatment clarified further, as there is some chance of confusion between the use of similar symbols for centrifuging and chemical treatment.

R. C. Paul.[6] The thought of the writer is that although some of the methods of calculation could be questioned and perhaps the individual items could be figured in different ways than that shown in the paper, the results clearly show that the cost of producing power was slightly over 14 mills per kw-hr., which is an item which should be interesting to all Diesel-engine men and interesting to producers of power.

Committee's Closure

To Mr. Thuerk: Mr. Thuerk will recall that last year's cost report presented only weighted averages. Due to some extent to his helpful criticism at that time, the committee decided to present, not only weighted averages, but arithmetical averages. The committee feels that the comparison of the two averages has a meaning for those who can see it. For instance, the weighted average fuel oil price of 4.18 cents per gallon compared with the arithmetical average of 4.19 cents tells at once that, so long as fuel oil is bought in tank cars, the small plant can buy as cheaply as the large one. On the other hand, the comparison of the weighted average attendance cost of 2.031 mills with the arithmetical average of 4.228 mills illustrates one advantage of the large plant quite forcibly.

The committee realizes that men not informed along engineering lines may be more misled than helped by averages. However, since this report is made to engineers, this consideration was waved aside. The committee is not decided upon the utility of this "median" value cited by Mr. Thuerk. Possibly it is much valued by statisticians. Certainly its use by engineers is not so extensive. It is probable that the committee should stop reporting averages altogether rather than attempt to add yet another brand (and perhaps more, if some one discovers them) with the alternative of an argument from the party whose thesis is damaged when one kind of average is discontinued.

In regard to publishing the high limits of costs as well as the low in the summary, the committee cannot agree that these high limits are of interest. The technical press has never considered inefficiency as news although efficiency always has been news. Any one can establish a new "high cost" record; not every one is able to break a "low cost" record.

In respect to a net kilowatt-hour basis for fuel and lubricating-oil consumption figures, the committee agrees with Mr. Thuerk that it might be more consistent to adopt this. However, this basis would restrict the tabulated results to plant averages (weighted), a situation which Mr. Thuerk should not prefer to actual data for individual units, for which only the gross output is known.

The information on fixed charges is fragmentary and should either be improved next year or discontinued. The committee feels that the proper course would be to list total investments as Mr. Thuerk suggests, where obtainable, and leave the selection of percentages to others. Since the primary aim was to arrive at the facts on production cost, the fixed charge information was not followed up as closely as it could have been, time permitting. Possibly some better plan can be worked out for next year's program. The committee also agrees that a classification of plants according to use would be of interest and shall devote some future attention to this matter.

The absence of information for some of the plants reporting last year is accounted for in the text of the report—either these plants made no report or submitted inconclusive data. The committee did not rule any one out on any other grounds. Possibly some of these plants were embarrassed by the more formidable questionnaire form.

The basis of the figures having been slightly changed this year from last, the committee felt that no useful purpose would be served by a direct comparison of last year's figures with this year's. Cost figures have been reduced to the net output basis instead of the gross, for instance, and maintenance figures include costs for the entire plant instead of for engines only. This change of basis may account for the increase in average cost noted by Mr. Thuerk.

To Mr. Hammond: As stated, probably the only fixed charge information we should attempt to collect is the total investment. Since the age of the plant is already an item called for, due allowance could be made for the date of installation.

To Mr. Kates: Some of the figures suggested by Mr. Kates are available from the report. Rated horsepower-hours per man-hour can be arrived at from Table 3, which lists the number of shifts and the attendants per shift. It is true that the hours per shift are not listed. However, all three-shift plants are 24-hr. plants, and there are only several that are not three-shift plants.

To Dr. Flowers: The committee realized when the questionnaire was framed that the lubricating-oil information requested was not complete. However, the danger of complicating the form with questions the average operator cannot answer was considered quite great enough as it was. Most operators know nothing about their lubricating oil except the name of the brand. If Dr. Flowers can recommend simple and concise questions

[5] Engineer in Charge of Development, De Laval Separator Co. Poughkeepsie, N. Y. Mem. A.S.M.E.

[6] McIntosh & Seymour Corporation, Auburn, N. Y. Assoc. Mem. A.S.M.E.

when the questionnaire is revised, we shall be glad to include them, however. We do not believe the information received will repay the effort, at least for the first year, but the innovation should have a definite educational value in that the operator's attention would be directed to the properties called for.

The symbols used in the text to describe lubricating oil treatment are explained at the bottom of Table 1. Those replying to the questionnaire were not in danger of becoming confused, for the reason that these symbols were not used on the form and were adopted in the report as a space-saving move only.

OGP-52-12

Purification of Diesel-Engine Lubricating Oil

By A. E. FLOWERS[1] and M. A. DIETRICH,[2] POUGHKEEPSIE, N. Y.

The paper is a continuation of earlier research on a 10 by 12 Diesel engine. Its most important novelty appears to be a reference to avoiding dilution of the lubricating oil from mechanical leakage, an explicit statement upon this subject being contained in the paper. Deterioration of the lubricating oil and its increasing contamination with various substances not originally present are again shown as a function of operating power, and emphasis is placed on the large percentage of products resulting from cracking. It is not stated, however, whether the cracking products are traceable to the fuel or to the lubricating oil.

IN a previous paper[3] the authors presented the effects of 1300 hours' operation on the lubricating oil of a Diesel-electric locomotive. This paper presents further results obtained during a 2300-hr. test run (16 weeks) on the same Diesel-electric locomotive equipped with a disk-type purifier operating continuously on a by-passed portion of the oil in circulation through the bearings and crankcase.

Samples of the oil were taken weekly from the purifier outlet and from the crankcase of the engine. These, together with the total quantity of sludge removed from the bowl of the purifier, were sent to the DeLaval Process Laboratory for examination.

Lubricating-Oil Data

Dilution. In all previous test runs dilution of the lubricating oil with fuel oil necessitated early removal of the oil. In this run, following some mechanical adjustments on the engine, no fuel dilution occurred during the 2300 hours of test, indicating that, in general, fuel dilution of the lubricating oil in Diesel engines is not a factor inherent in the engine and occurs only because of some accident or some improper mechanical adjustment.

Oil Condition. The condition of the lubricating oil after stated intervals of service was found to be as indicated in the following table:

	New oil	Hours of service 1000 hr.	2000 hr.	2300 hr.
Sediment (by volume), per cent	Trace	0.70	1.00	....
Ash (by weight), per cent	None	0.015	0.019	0.020
Specific gravity at 60 deg. fahr.	0.896	0.899	0.897	0.897
Flash point, deg. fahr.	445	410	380	385
Fire point, deg. fahr.	500	495	455	450
Pour point, deg. fahr.	30	35	30	35
Viscosity at 100 deg. fahr., Saybolt universal seconds	554	622	548	519
Neutralization number	0.01	0.86	0.47	0.83
Conradson carbon residue	0.65	1.19	1.05	0.97

Sediment. The per cent sediment in the oil rose fairly rapidly to 0.70 per cent by volume at the end of 600 hr. It remained constant at this value until 1300 hr. of service had been reached. The value then rose very gradually to 1.2 per cent by volume at the end of the test. For *this oil* it appears that an equilibrium value between the rate of sediment formation and the rate of its removal either does not exist or is not reached until after a much more prolonged service period. In other tests of this kind equilibrium values have been reached, and there seems no reason to doubt that further tests will reveal an equilibrium condition.

Ash. The per cent of ash in the oil remained between approximately 0.01 and 0.02 per cent by weight throughout the test.

Neutralization Number. The neutralization value of the oil during service showed very marked fluctuations. No good reasons can be given at present for this fluctuation.

Carbon Residue. The Conradson carbon residue of the oil rose to a value of approximately 1.00 per cent at the end of 1140 hr. and stabilized at this value (within reasonable variations) for the remainder of the test.

Cracking and Oxidation. The major changes which the lubricating oil showed in service are similar to those caused by "cracking" and by oxidation of the oil. Analyses of the oil and sludge indicate that "cracking" plays a greater part in the oil deterioration than oxidation. The changes which occur in the oil are not greater than would normally be expected under the operating conditions to which the oil is subjected. The per cent of oxidized, asphaltic, resinous material dissolved in the oil, as measured by precipitation with normal benzine, was very low and showed no appreciable increase between 1000 and 2300 hr. of service.

Engine and Purifier Operating Data

The lubricating-oil requirements of the engine during this 2300-hr. period were:

Make-up oil required per 100-hr. operation, gal.	2.00
Total oil consumption per 100-hr. operation, gal.	4.35

A summary of the data on the operation of the disk-type purifier is as follows:

Average time of run between bowl cleanings, hr.	77
Average quantity of oily sludge removed per bowl cleaning, grams	344
Mean rate of sludge removal per 100-hr. engine operation, grams	455 (400 cc.)
Mean rate of *dry weight* sludge removal per 100-hr. engine operation, grams	200

Engine Condition. This run was brought to a close because of mechanical failure of connecting-rod bearing No. 3. Some of the oil-feed passages were found partially clogged by deposits along the walls, which may have occurred during this or earlier runs made without oil purification. The bright parts of the

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[1] Engineer in Charge of Development, DeLaval Separator Company. Mem. A.S.M.E. Dr. Flowers received his M.E. from Cornell University in 1902, his M.M.E. in 1914 and his Ph.D. in 1915. From 1904 to 1912 he served as instructor and assistant professor of electrical engineering at the University of Missouri, and later held the chair of electrical engineering at Ohio State University. During the War he held the commission of captain in the Signal Corps of the Army and afterward was connected with the engineering department of the National Aniline & Chemical Co. and the Chemical Machinery Construction Co. He has been associated with his present concern since 1923.

[2] Process Chemist in Charge of Process Laboratory, DeLaval Separator Company. Mr. Dietrich received the degree of A.B. in 1921 from Oberlin College and in 1924 his A.M., the following year receiving an A.M. from Princeton University. Since his graduation he has been associated with his present firm.

[3] "Service Characteristics of Diesel Engine Lubricating Oil," presented at the Annual Meeting of The American Society of Mechanical Engineers, December 2 to 6, 1929, New York, N. Y.

Presented at the National Oil and Gas Power Meeting, State College, Pa., June 12 to 14, 1930.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

crankcase sides were covered with a thin black coat. This suggests that there may be a tendency for some of the cracked or oxidized residues to deposit on walls or upon oil passages, and special tests upon this point are to be carried out immediately. Deposits of this nature are not *necessarily* to be expected, as some Diesel engines have been found after a year's operation with crankcase walls and finished surfaces of running parts as bright and clean as new, when equipped with disk-type purifiers on the lubricating-oil system.

Wear. Measurements of clearances of the bearings at the end of the test (2300 hr.) showed no measurable changes in the main bearings. Measurements of clearances on the connecting-rod bearings at the beginning and end of the test are as follows:

Bearing No.	Clearance, in inches, at Start of test	2000 hr.	2300 hr.
1	0.005	0.006	0.008
2	0.005	0.006	0.007
3	0.005	0.006	Gone
4	0.005	0.006	0.006
5	0.005	0.005	0.006
6	0.005	0.006	0.007

These values compare very favorably with the average wear of 0.001 in. per month (or about 700-hr. operation) before using the disk purifier.

Purification Rate. The purified-oil throughput was about 15 per cent of the oil circulated to the bearings, and this rate was sufficient to purify an amount equal to the content of the crankcase about every 5 hours.

Data on Sludge Analysis

Sludge Particles. The curves for rate of removal of sludge and carbonaceous material per 100-hr. operation pass through several maxima and minima. This indicates that the "carbon" particles gradually grow in size or agglomerate until they reach a size where they can be removed by the purifier, following which the process is repeated. After each such cycle of agglomeration it appears so far that the particles left in the oil are finer than those present during the preceding cycle.

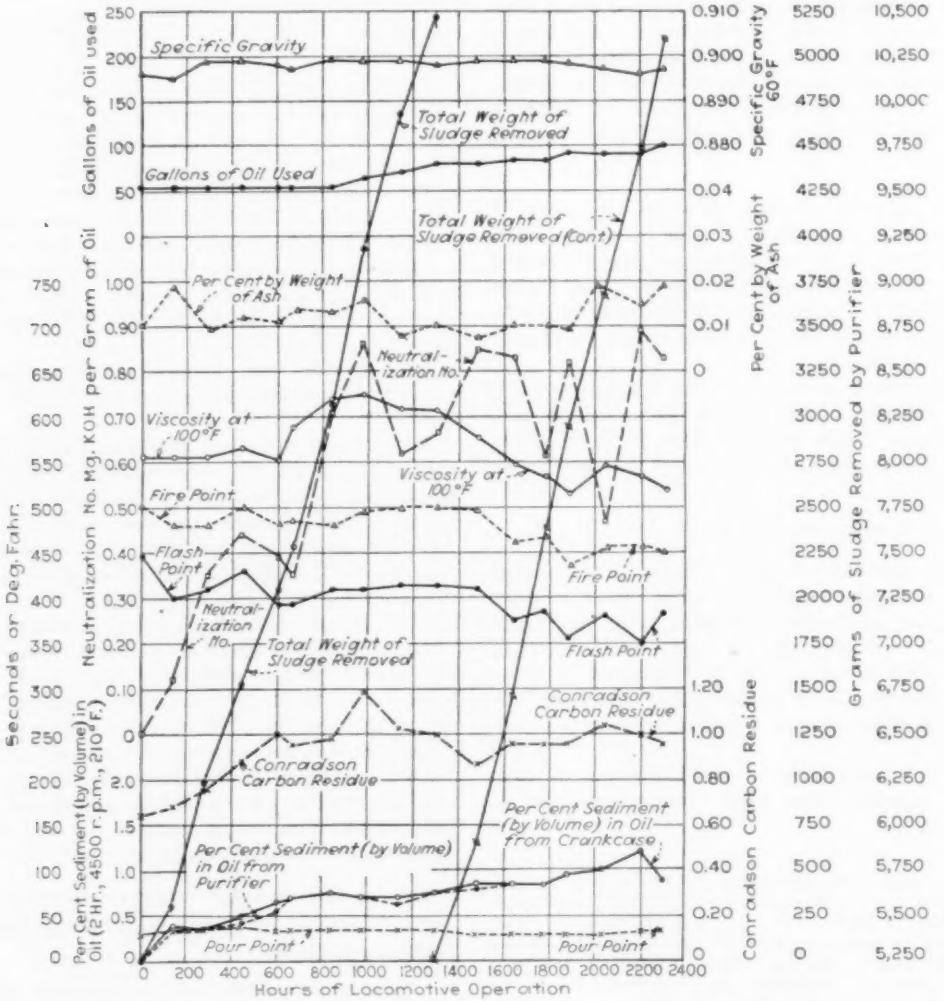


FIG. 1 EFFECT OF SERVICE ON CHARACTERISTICS OF LUBRICATING OIL USED ON DIESEL-ELECTRIC LOCOMOTIVE, EQUIPPED WITH PURIFIER

Metallic Oxides. After the pistons had been run in (during the first 30 hr. of test), the average rate of removal of metallic oxides was 12 g. per 100-hr. engine operation. This value checks fairly closely the value of 10 g. obtained during a previous test run of 1369 hr. on this locomotive and indicates only slight wear on the engine parts.

Silica. The rate of silica removal remained at the usual amount of 1.5 to 2.0 g. per 100-hr. engine operation.

Fuel Dilution

One explanation for the fuel dilution observed in previous

runs was found when reconditioning the engine prior to this test. On dismantling the Diesel engine it was discovered that the ground joints between the cylinders, combustion chambers, and cylinder heads were not tight. This allowed fuel oil to leak out around the cylinder studs and into the crankcase through the pushrod crosshead guides. Also the air-starting valves in the cylinder heads were leaking, allowing fuel oil to get past and run into the crankcase. Correction of these mechanical troubles eliminated fuel dilution during this test.

Description of Diesel Engine

A description of the Diesel engine used in the test is as follows:

Brake horsepower, 300
Speed maximum, 600 r.p.m.
Cycle, four-stroke
Number of cylinders, 6

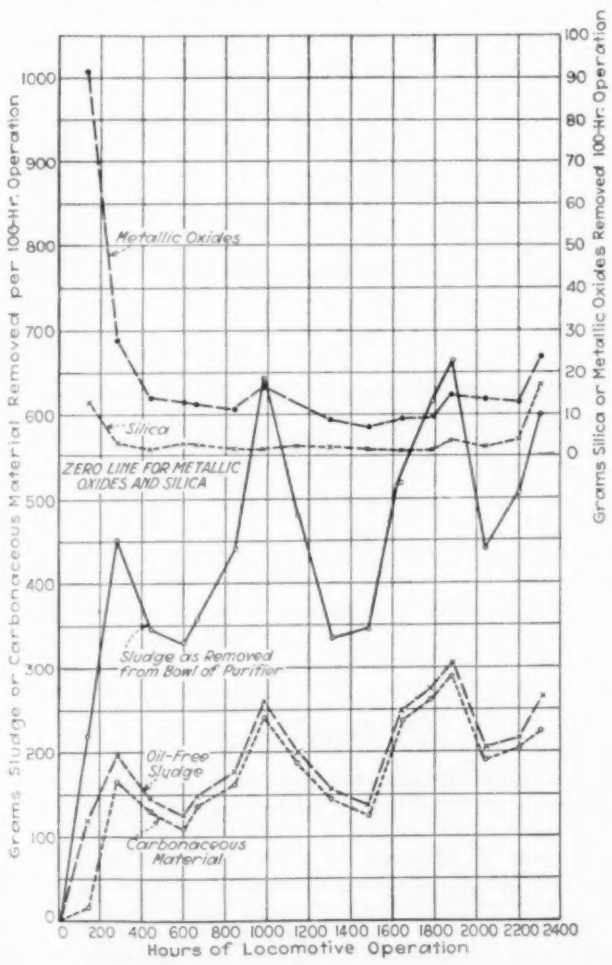


Fig. 2 Analyses of Sludge Removed From Bowl of Purifier on Diesel-Electric Locomotive, Equipped With Purifier

Arrangement, vertical
Bore, 10 in.
Stroke, 12 in.
Piston speed, 1200 ft. per min.
B.m.e.p., 70 lb. per sq. in.
Weight, 20,125 lb.
Length overall, 10 ft.
Height from base, 7 ft.
Width overall, 4 ft.
Method of starting engine, motor generator
Fuel injection, direct
Injection pressure, 3000 lb. per sq. in.
Fuel distribution, rotating distributing valve and feed pump
Lubrication, forced feed
Lubricating-oil purification, disk-type purifier
Quantity of oil in engine, 54 gal.
Rate of oil circulation through oil pump, 12 gal. per min. (720 gal. per hr.)
Rate of oil circulation through purifier, 11 gal. per hr.
Cooling of engine, water cooled
Cooling-water inlet temperature, 150 deg. fahr.
Cooling-water outlet temperature, 160 deg. fahr. (Regulation of normal outlet temperature depends on air blast delivered by cooling-system blowers.)

The locomotive was used during the 16 weeks' test for railroad switching service.

Description of Disk-Type Purifier

A description of the disk-type purifier is as follows:

Rates speed of bowl, 7000 r.p.m.
Number of disks, 21
Calk thickness, 0.050 in.
Diameter of disk, 120 mm.
Type of disk, solid

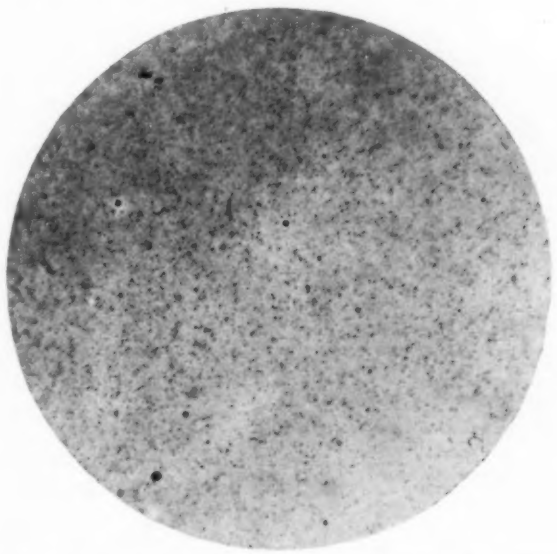


Fig. 3 Photomicrograph of Lubricating Oil From Crankcase of Diesel-Electric Locomotive × 470

Motor data, compound wound, d.c., 1750 r.p.m., 220 volt, approximately 1/3 hp. rating
Motor pulley (to purifier) dimensions, 155 mm. outer diameter
Purifier pulley dimensions, 37.5 mm.
Purifier oil pump, positive delivery, 1/8-in. pipe connections
Oil throughput through purifier, 11 gal. per hr.

Methods

Tests on the used oils were conducted according to the latest A.S.T.M. methods, as follows:

Specific gravity	D287–28T
Viscosity at 100 deg. fahr.	D88–26
Flash point	D92–24
Fire point	D92–24
Conradson carbon residue	D189–28
Pour point	D97–28
Neutralization number	D188–27T

Sediment. The per cent sediment was determined by centrifuging 100 cc. of oil at the very high speed of 4500 r.p.m. on a 16-in. circle and 210 deg. fahr. for 2 hours.

Ash. Per cent ash was determined by igniting and burning 30 to 50 grams oil to constant weight.

TABLE 1 ANALYSES OF SLUDGE SAMPLES BY EXTRACTION ON AN OIL-FREE BASIS

	Hours of service 979 hr.	2199 hr.
Benzole soluble, by weight, per cent	22.8	27.0
Chloroform soluble, by weight, per cent	3.3	2.3
Carbonaceous material insoluble in above solvents, by weight, per cent	66.6	62.8
Ash, by weight, per cent	7.3	7.9

TABLE 2

Length of service, hr	979	2040	2300
Precipitated material, per cent by weight	0.0112	0.0104	0.0116

decomposition products in the oil are the result of "cracking," which is due to the high temperatures that are met with in the engine.

TABLE 3 EFFECT OF SERVICE ON CHARACTERISTICS OF LUBRICATING OIL USED ON DIESEL-ELECTRIC LOCOMOTIVE EQUIPPED WITH PURIFIER

Sample No.	Quantity of oil added to system, gal. Single addition	Quantity of oil added to system, gal. Cumulative	Date of taking sample	Hours of service between samples	Cumulative hours of service	Rate of oil circulation	Per cent sediment in oil found by centrifuging at 210 deg. fahr. and 4500 r.p.m. for 2 hr. From crankcase	Per cent sediment in oil found by centrifuging at 210 deg. fahr. and 4500 r.p.m. for 2 hr. From purifier	Specific gravity at 60 deg. fahr.	Saybolt viscosity at 100 deg. fahr., sec.	Flash point, deg. fahr.	Fire point, deg. fahr.	Conradson carbon residue, per cent by weight	Pour point, deg. fahr.	Neutralization number, mg. KOH per gram oil	Weight of dirt removed each run by purifier, grams	Cumulative weight of dirt removed by purifier, grams	Hours of purifier operation during run
	54[5]		10–22–29	0	0	...	Trace	..	0.896	554	445	500	0.65	30	0.01	....	....	....
1[1]	0	0	10–29–29	137	137	11 g.p.h.	0.38	0.35	0.895	556	400	480	0.68	35	0.12	300	300	137
2	0	0	11– 5–29	148	285	11 g.p.h.	0.35	0.35	0.899	556	410	480	0.75	35	0.35	670	970	148
3	0	0	11–12–29	157	442	11 g.p.h.	0.50	0.42	0.899	566	430	500	0.89	40	0.44	542	1512	157
4	0	0	11–19–29	159	601	11 g.p.h.	0.65	0.55	0.898	551	395	480	1.00	35	0.39	529	2041	159
5	0	0	11–26–29	63	664	11 g.p.h.	0.70	0.70	0.897	588	395	485	0.95	35	0.35	225	2266	63
6	0	0	12– 3–29	182	846	11 g.p.h.	0.75	..	0.899	620	410	480	0.98	35	0.71	802	3068	175
7	10	10	12– 9–29	133	979	11 g.p.h.	0.70	0.70	0.899	622	410	495	1.19	35	0.86	856	3924	105
8	6	16	12–16–29	161	1140	11 g.p.h.	0.70	0.65	0.899	608	415	500	1.02	35	0.63	757	4681	161
9	10	26	12–23–29	157	1297	11 g.p.h.	0.75	0.75	0.898	606	415	500	0.99	35	0.66	537	5218	157
10	0	26	1– 6–30	197	1484	11 g.p.h.	0.85	0.80	0.899	573	410	495	0.86	30	0.85	682	5900	197
11	4	30	1–13–30	157	1641	11 g.p.h.	0.85	0.85	0.899	549	375	460	0.97	30	0.83	806	6706	157
12	0	30	1–20–30	147	1788	11 g.p.h.	0.80	..	0.899	534	385	465	0.96	30	0.61	907	7613	147
13	8	38	1–27–30	91	1879	11 g.p.h.	0.95	..	0.898	516	355	435	0.96	30	0.82	605	8218	91
14[2]	0	38	2–10–30	161	2040	11 g.p.h.	1.00	1.00	0.897	548	380	455	1.05	30	0.47	709	8927	161
15[3]	0	38	2–17–30	159	2199	11 g.p.h.	1.20	1.20	0.896	537	350	455	1.01	35	0.89	810	9737	151
16[4]	8	46	2–24–30	101	2300	11 g.p.h.	0.90	..	0.897	519	385	450	0.97	35	0.83	604	10341	101

[1] 30 hours out of 137 used for running in pistons.
[2] Engine out of service two weeks for inspection and minor repairs.
[3] Viscosity on uncentrifuged oil, 532 seconds.
[4] Viscosity on uncentrifuged oil, 526 seconds.
[5] New oil put into system, 10–22–29.

TABLE 4 ANALYSES OF SLUDGES REMOVED FROM BOWL OF PURIFIER ON DIESEL-ELECTRIC LOCOMOTIVE

Date removed	10–29–29	11–5–29	11–12–29	11–19–29	11–26–29	12–3–29	12–9–29	12–16–29	12–23–29	1–6–30	1–13–30	1–20–30	1–27–30	2–10–30	2–17–30	2–24–30
Sludge as Removed From Bowl																
Per cent by weight of oil	46.3	56.5	58.1	62.0	58.3	60.8	59.5	57.2	54.9	60.8	51.5	55.7	53.9	53.7	56.9	55.6
Per cent by weight of carbonaceous material	6.0	36.6	37.3	33.3	37.5	36.3	37.6	39.6	41.8	36.8	46.4	42.5	43.6	43.1	40.1	37.5
Per cent by weight of metallic oxides	41.8	6.3	4.1	3.9	3.5	2.5	2.6	2.7	2.7	2.0	1.8	1.6	1.9	2.7	2.2	4.0
Per cent by weight of silica	5.9	0.6	0.5	0.8	0.7	0.4	0.3	0.5	0.6	0.4	0.3	0.2	0.6	0.5	0.8	2.9
On Basis of Oil-Free Sludge																
Per cent by weight of carbonaceous material	11.2	84.1	89.0	87.6	89.9	92.6	92.8	92.5	92.7	93.9	95.6	95.9	94.6	93.1	93.0	84.5
Per cent by weight of metallic oxides	77.8	14.5	9.8	10.3	8.4	6.4	6.4	6.3	6.0	5.1	3.7	3.6	4.1	5.8	5.1	9.0
Per cent by weight of silica	11.0	1.4	1.2	2.1	1.7	1.0	0.8	1.2	1.3	1.0	0.7	0.5	1.3	1.1	1.9	6.5
Ratio of "carbon" to metallic oxides	0.14	5.8	9.1	8.5	10.7	14.5	14.5	14.7	15.4	18.4	25.8	26.6	23.1	16.1	18.2	9.4

Data

Data on the changes in characteristics of the oil and analyses of sludge are given in the accompanying charts (Tables 3 and 4 and Figs. 1, 2, and 3).

The data given in Table 1 indicate from the low percentage of material insoluble in both benzole and chloroform that the sludge consists largely of heavy cracked material rather than oxidized materials such as resins or asphalts.

Oil Analysis by Precipitation Number. In order to determine whether the used oil contained an appreciable quantity of dissolved oxidized material, 25 grams of the used centrifuged oil were diluted with 250 cc. Holde's normal benzine (equivalent to A.S.T.M. precipitation naphtha) and allowed to settle 4 hr. at room temperature (25 deg. cent.), filtered through a Gooch crucible and weighed.

The data given in Table 2 show that the quantity of dissolved oxidized product in the oil is small and that it has not increased with length of service, at least between 1000 hr. and 2300 hr. The quantities of soluble oxidized materials reported in Table 2 do not seem to be sufficient to have saturated the oil with respect to them and may be taken as further indication that the main

Discussion

WINSLOW H. HERSCHEL.[4] What is the explanation for the increase in silica and metallic oxides toward end of text?

CHARLES W. STAPLES.[5] If dilution did not occur, why did viscosity fall off? Are metals removed from engine as oxides?

ROBERT C. HARDY.[6] (1) Initial increase in viscosity may have been due to oxidation together with suspended matter present. (2) If no fuel dilution occurred, decrease in viscosity, flash point, and fire point in latter part of run was evidently due to dilution with products of the cracking indicated by the character of the sludge (Table 1). (3) Wear in connecting rod bearings was much more rapid in last 300 hr. than in first 2000 hr. The increase in metallic oxide in sludge in last part of test is probably the result of which the increase in silica content may have been the cause. (4) What was oxidation number of the new oil? If it was low, the apparently minor

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[5] Associate Engineer, Bureau of Standards, Washington, D. C.
[6] Assistant Chemist, Bureau of Standards, Washington, D. C.

part played by oxidation in this test does not indicate that oxidation test is not important. (5) Apparent lack of relationship between various test results might be removed if proper compensation could be made for the effect of various factors such as addition of new oil and periods of idleness.

Authors' Closure

Regarding the comments on the percentage of metallic oxides in the sludge at the beginning of the test, it is well to bear in mind that in every test of this kind which we have run so far, we find a larger percentage of metal, metallic oxides, and silica during the first few days of operation of the engine on any test run.

The question regarding the causes of fuel dilution in previous test runs and their elimination in the present test run is answered in the paper under the paragraph entitled "Fuel Dilution."

Relative to the deposition of carbon or sludge in the oil-feed passages, we have tests under way which we hope will disclose some of the factors governing deposition of sludge.

This test run was made with the cooperation of the representatives of the owners of the locomotive who controlled the addition of make-up oil. The amount of oil in the crankcase was kept fairly constant by means of the oil-level gage.

There appears to be no explanation for the increase in metallic oxides toward the end of the test, other than the fact that extra rapid wear of some of the engine parts may have then been taking place. Metallic material is present in the engine oil, both in the metallic form and also as oxides. In the methods of analysis used herein they are determined as oxides.

Decrease in viscosity of the oil during the latter part of the test may be due to the fact that *no* new oil was added during the first 979 hours of test, after which (in the last 1321 hours) 146 gallons of make-up oil were added. From the examination of the data, it will be seen that the viscosity of the oil started to decrease after the first addition of make-up oil. The slight increase in viscosity also occurred during the months of October and November, during which time the weather was warmer than in the latter part of the test. The possibility exists that in the warmer weather the more volatile products resulting from "cracking" were evaporated off, while in the colder months they were partially condensed and kept in the crankcase.

We believe that the constant quantity of silica found in the sludge is due to contamination from the air. Any increase in the silica content at the close of the test may be due to an abnormal contamination of the air. Mr. Hardy's suggestion that the increase in silica content may have been the cause of the wear may have some basis, but it must be kept in mind that other and more powerful causes are also present to explain wear, just before the wear-out of a bearing liner.

The Sligh oxidation number of the new oil was 10 mg. per 10 g. oil. This is generally regarded as a very low oxidation number for an oil of this viscosity.

The results given in this paper were based upon actual service conditions of a Diesel-electric locomotive in switching service.

OGP-52-13

Power Plant and Diesel Generating Installation of R. H. Macy & Co., Inc.

By GEORGE D. POGUE,[1] NEW YORK, N. Y.

To meet the demand for electricity for lighting, elevators, escalators, ventilating fans, etc., in Macy's store, New York City, two Diesel-driven units each of 1000 b.hp. are used. The rates for purchased power were such that it could not be considered in comparison with a company-owned plant. The author in this paper describes the load demands and shows the advantages of Diesel-driven units in addition to steam-driven units.

THE DEPARTMENT store of R. H. Macy & Co. in New York City has enjoyed a very rapid growth. The business was started in 1858 and moved to its present site at Broadway and Thirty-fourth Street in 1902. The original unit on this site provided 1,012,500 sq. ft. of floor area, or 16,600,000 cu. ft. Additions have been made from time to time, and the latest addition at the close of 1929 increased the total floor space to approximately 1,600,000 sq. ft., and the volume to about 26,000,000 cu. ft. These buildings occupy more than three-quarters of a city block. Recently almost the entire remainder of the block has been taken over, which will increase the floor space to nearly 2,000,000 sq. ft. and the building volume to about 31,500,000 cu. ft.

From the very beginning, all electrical energy and steam have been generated on the premises, no occasion having arisen for even temporary use of breakdown service from the outside. The increase in load has more than paralleled the increase in building space owing to the enhanced demand for electrical energy for lighting, elevators, escalators, ventilating fans, etc. The original boiler installation of 2720 boiler hp. has been increased from a total capacity of 2000 kw. in 1902 to 3350 kw. in 192€, the present equipment consisting of four 400-kw., two 750-kw., and one 250-kw. compound steam engines. At the same time the boiler output was greatly increased by substituting fuel oil for coal.

This permitted the output of the boilers to be pushed up to a maximum of 150 per cent, although 125 per cent is the rate now maintained in the interest of keeping down maintenance expense on the furnaces. It was only after the power demands of recent years began to exceed all expectations that the addition of a 565-hp. boiler became unavoidable. With fuel oil obtained under contract at less than 4 cents per gallon and coal costing about $6.70 per ton, the greater efficiency of the oil-burning system and reduction of the fireroom payroll resulted in a saving of about $20,000 per year, not counting the elimination of $4000 worth of ash-removal service. Notwithstanding these good results, the addition of further boiler and steam-generating capacity would meet with extraordinary difficulties due to lack of space, while the excess of unused exhaust steam would be further added to. The relatively high cost of city water for condensing, $1 per 1000 cu. ft., is a further consideration opposed to the enlargement of the present steam-generating capacity. At present one of the factors favoring the use of condensers at all is the necessity for maintaining a high vacuum on the turbo-refrigerating units, which are fed with exhaust steam at about 0.5 lb. per sq. in. pressure and which exhaust into a vacuum of about 24 to 26 in.

Only a partial idea of the rapid load increase faced by those in charge of the Macy power plant is given by the phenomenal increase in building space already outlined. Parallel with this the rate at which the store space already in use is increasing its demand for power has been startling, the increase from 1928 to 1929 alone being from 9,433,845 to 11,459,691 kw-hr. Many a sizable city requires less current than this per year. About half of the electrical output is used for lighting, while the remainder is consumed in motors driving more than 40 escalators, an equal number of elevators, and other services. The installed capacity of the motors in the heating and ventilating system is approximately 1000 hp., 275 hp. in the air-conditioning system, 250 hp. in the refrigerating plant, 350 hp. in the pneumatic-tube system, and 90 hp. for the package conveyors. Exhaust steam from the engines is partially used for building and service-water heating and for two 410-hp. turbo-refrigerating machines of 350 tons capacity each. Although between 20 and 40 per cent of the exhaust steam is therefore utilized in summer and winter, more than half of it at present is discharged into the atmosphere. From the brief outline of equipment given here it is apparent that the interrelations among the component parts is complex and varies from day to day. A really thorough study would require that each day's record in a given year be analyzed by itself and, although the remarkable power-plant bookkeeping system in force at the Macy store has provided the basis for doing this, the presentation of the data, if handled in this manner, would require not one paper but a long series of them.

One of the factors which contributed to the rapid increase in load is the air-conditioning system placed in service in June, 1929. Electric motor-driven pumps aggregating 115 hp. circulate the water while seven fans driven by motors of some 160 hp. total capacity circulate the air. A substantial part of the heavy demand for water which the store draws from the city supply system on hot summer days, approaching 100,000 cu. ft. per day, and costing close to $100, is attributable to the air-conditioning system. Steam-heating elements placed in the air ducts are provided for warming the air in cold weather.

Another modern feature of this unique store is the incinerator installation consisting of two units. They are rated to consume 1600 lb. of rubbish per day, but it has been found possible to operate them at a considerably higher rating than this. One of them is fitted with economizer tubes, which deliver water to the boilers at approximately 265 deg. fahr. A large feed-water heater handles the returns from the various heating systems, including the service-water heaters, as well as the condensate from the condensers on the turbo-refrigerating units. It is important to observe that the problem of keeping books on functioning of the entire thermal system of the Macy power and heating plant is an exceedingly complex one.

During the early part of 1929 the management realized that additional generating capacity would have to be installed, but

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Presented at a meeting of the Metropolitan Section, New York, N. Y., April 30, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

as the sub-basement was already crowded to the limit with power equipment the problem of selecting the additional apparatus necessitated an elaborate study. The decision was finally reached to utilize a space approximately 19 ft. wide by 90 ft. long with 15 ft. head-room. Until then this had been occupied by surge tanks needed for the hydraulic elevators which had been installed in the original building and which had just been replaced with electric elevators. Practically no other space was available at that time, and the question of supplying additional power-generating equipment became focused on making the

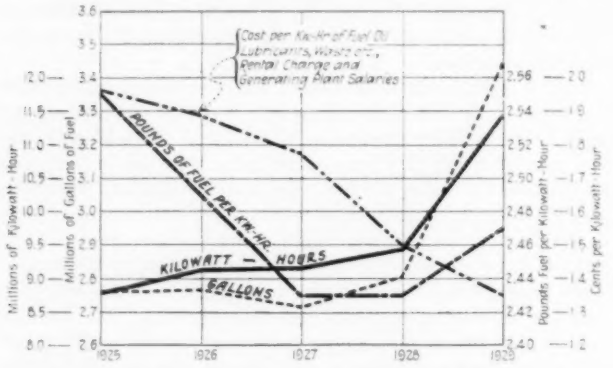


FIG. 1 PLANT CONDITIONS FOR FIVE YEARS' OPERATION

15 ft. by 19 ft. by 90 ft. space yield the greatest possible capacity. Two Diesel engines of 1000 b.hp. each gave the answer to the question. Another solution would have been to purchase power from a public-utility company, but this did not receive serious consideration on account of the prevailing rates for the class of service involved. The Diesel engines also gave promise of meeting other urgent conditions in the power-supply system of the Macy store more satisfactorily than any steam prime mover. The figures relating to water consumption, power distribution, and heat balance given here are intended rather as an aid to visualizing the broader aspects of the situation than to represent an accurate balance sheet of the conditions.

The almost spectacular way in which conditions change is illustrated in Fig. 1, which covers five representative years, beginning with 1925, of operation with oil fuel under the boilers. The effects of building and equipment additions, and above all the increase in business done by the store, are represented. Most striking is the increase in electrical output, which rose from about $8^3/_4$ to $11^1/_2$ million kw-hr. per year. Paralleling this is the rise in total fuel consumed, but the improvements in equipments show up as a decided drop in the specific rate of fuel consumption. Only as the total output begins to overtax the facilities does the specific fuel consumption rise, but not nearly in proportion to the extra energy produced. Most remarkable is the consistent fall in overall cost per kw-hr. generated, which includes the expense for fuel, lubricants, waste, rental charge, and salaries paid to employees of the generating plant. This figure includes no repair costs, which were rather difficult to arrive at for the years prior to 1928. For the latter year and for 1929, respectively, the total cost, including repairs and maintenance, was 1.603 and 1.504 cents per kw-hr. However, no credit was given for exhaust steam utilized for heating and for the operation of the air-conditioning system. The cost of generating this steam separately is roughly estimated at $37,000 per year and would, if credited, reduce the cost per kw-hr. by something like 2 mills. Whatever the significance of this figure may be, it must be conceded that $1^1/_2$ cents per kw-hr. is a phenomenally low figure in consideration of the fact that about $2^1/_2$ lb. of steam fuel are consumed per kw-hr. put on the switchboard. This amounts to only about 3.3 kw-hr. per gallon, and reflects in a highly complimentary manner on the heat economics of the plant as a whole. No allowance is made for capital charges, in view of the fact that the greater part of the equipment is more than 27 years old and therefore written off the books for all practical purposes.

Another feature which throws the remarkable operating economy of the plant into sharp relief is the fact that a considerable amount of exhaust steam is thrown into the atmosphere, even on the coldest winter days when the heating system makes its maximum demand. Were it not for the good management already referred to, this lack of balance between the heat and the power load would interfere with good economy, particularly in view of the fact that the weight of the steam exhausted is more than half the total weight of water fed to the boilers. An approximate representation of the water balance as it now stands is given in Fig. 2A. According to this estimate, only $^1/_3$ of the water entering the boilers is condensate, the remaining

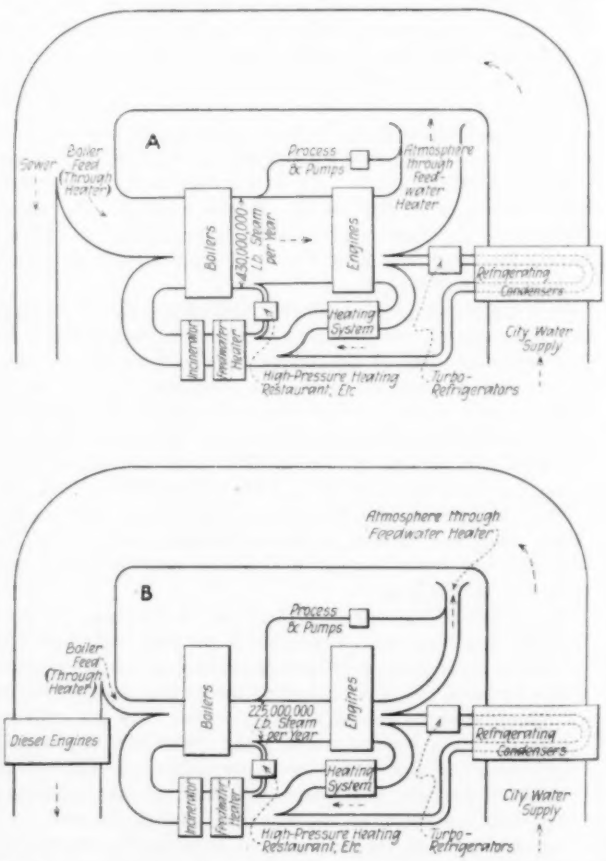


FIG. 2 APPROXIMATE WATER AND STEAM CIRCULATION; A, PRESENT CONDITIONS; B, WITH DIESEL ENGINES

$^2/_3$ being obtained from the city supply system through the feedwater heater, economizer, and condensers. To balance this an almost equal quantity of steam is exhausted into the atmosphere.

Of the total amount of steam generated about 94 per cent is supplied to the steam-driven generators. Some, but not all of the high-pressure heating steam, such as that supplied to the restaurant, comes back in the returns. Of the steam passing through the engines approximately 66 per cent is exhausted to the atmosphere, while the remaining 34 per cent of this quantity (not of the total) is utilized partly for heating or air conditioning

and returns to the feedwater heater. In view of the condition shown here it is apparent why the addition of further steam-generating equipment to take the added electrical load was not looked upon with favor, quite independently of space considerations.

Large quantities of cooling water are required for the steam condensers on the turbo-refrigerating apparatus as well as for the refrigerant condensers. However, as these units are operated with exhaust steam that would otherwise go to waste, the cost of cooling water, therefore, represents virtually the principal operating charge against them. The net cost of the very considerable amount of power required is probably considerably lower than it would be if obtained in any other way.

Operation With Diesel Engines

As a general basis for estimating the manner in which the Diesel engines may be expected to fit into the rather complex scheme of power supply, heating, and ventilating system of the Macy store the daily load curves shown in Fig. 3 have been plotted on the basis of actual meter readings. Extreme summer and winter days were selected, with the remarkable result that the electrical demands for the two are found to lie quite close together. "Daylight saving" seems to have little effect on the lighting requirements of a large department store, while the slight reduction in the summer population of the store is virtually without effect on the operation of elevators and escalators. The demand for boiler make-up water, however, is materially

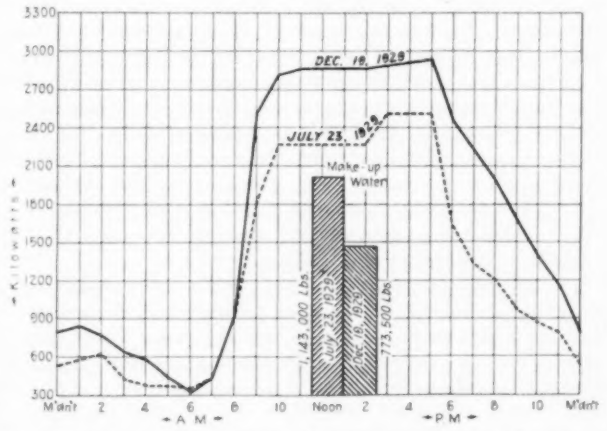


Fig. 3 Daily Load Curves for Summer and Winter Compared

reduced, mainly on account of a fall in the demand for heating steam.

One of the most important results expected from the installation of the Diesel engines will be the provision of stand-by power, which is not now as ample as desired. The installed capacity of the steam units is only 3350 kw., and now requires that all the available units be operated during the periods of higher load. A further consequence of operating the Diesel engines will be a reduction in the weight of water handled through the boilers and consequently of the amount of steam exhausted to atmosphere. An inspection of Fig. 4 shows how the combined outputs of the Diesel engines and some of the steam units may be expected to take the total load. Even with the Diesel engines running at maximum capacity during the peak period and with the steam output correspondingly reduced it is estimated that there will still be a noticeable surplus of exhaust steam. An indication of how this might work out is given in Fig. 3B. The total steam generated in the boilers is expected to be reduced by something like 50 per cent, but as there appears to be use for only about 35 per cent, a certain margin will still remain. The curves in Fig. 4 are based on a winter day, so that in summer the effect of the Diesel engines in reducing the amount of steam generated should be even more pronounced at times when less use can be made of the exhaust steam.

Owing to the high load factor of the Diesel engines it is probable that they will produce something like 11.5 to 12.5 kw-hr. per gallon of fuel, as against only about 3.3 kw-hr. per gallon of fuel used in the steam-generating equipment. The total elec-

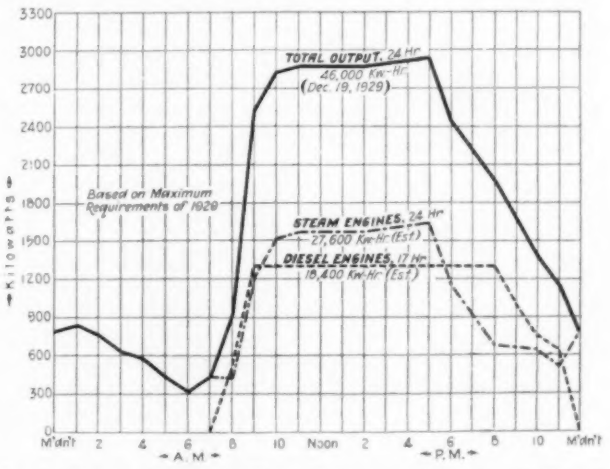


Fig. 4 Graphs Showing How Combined Outputs of Diesel Engines and Steam Units Are Divided

trical output for 1929 was close to 11.5 million kw-hr. and the corresponding consumption of fuel oil 3.5 million gallons. If the Diesel engines had then been available it would have been economical on the basis of the load curves shown in Fig. 4 to produce with them something like 5.5 million kw-hr. per annum. For the steam plant's share of the load approximately 1.8 million gallons of fuel oil would be consumed, while the Diesel engines would generate their share on about 0.4 million gallons and the combined total would be 2.2 million gallons. This reduction is not directly proportional to the cost saving, which is difficult to compute in the absence of official data on the cost of boiler and Diesel fuel. However, no great mistake will be made by assuming $3^3/_4$ cents per gallon as the cost of the boiler fuel and $5^1/_4$ cents as that of the Diesel oil. On this basis about $20,000 would have to be spent on Diesel fuel and $67,000 on boiler oil, or $87,000 altogether, contrasting with about $125,000 that would be spent if steam only were used. The net saving of $38,000 on fuel will naturally be offset to a certain extent by charges other than fuel to be booked against the Diesel engines. Among these are floor space rental, lubricating oil, labor, cooling water, maintenance, and amortization, but their total, in terms of cents per kw-hr. generated by Diesel power, will of course come well within the overall kw-hr. cost recorded for the steam-generating units.

After the Diesel engines are in commission, additional use is to be made of the water now partly fed to the boilers and partly running to waste at a cost per refrigerating season of about $7500, for the Diesel-engine jacket-cooling system has been piped up to the discharges from the turbo-refrigerating condensers, which yield about 670,000 gal. of water per day when operating at full capacity. If the daily output of the Diesel plant is as estimated in Fig. 4, that is, 18,400 kw-hr. or 29,200 b.hp-hr., cooling water will be supplied at the rate of some 23 gal. per b.hp-hr., a supply which should be adequate even after making due allowance for the fact that the condenser water reaches the engines at a temperature close to 115 deg. at times of peak demand on the refrigerating system. A branch line is provided to

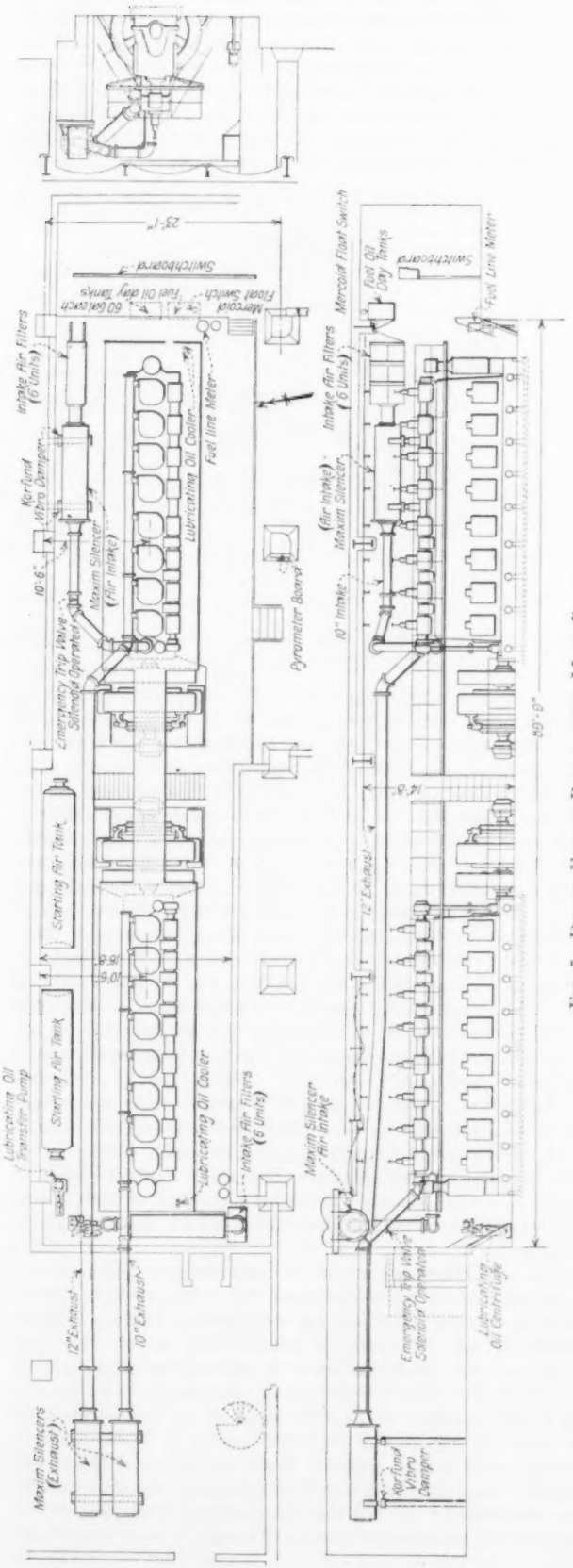


FIG. 5 DIESEL-ENGINE ROOM AT THE MACY PLANT

feed cold water into the Diesel-engine jackets direct from the city supply system when required and is fitted with a Powers automatic regulator and check valve to act without attention whenever the temperature of the water discharged from the Diesel engines exceeds a set limit. A small cold-water line also goes to the injection air compressors and oil coolers, in view of the fact that this equipment would not ordinarily work efficiently with the water temperature expected. Individual distant-reading dial thermometers are provided for each of the cylinder-water discharges on the engines, so that their temperatures may be individually regulated with the valves fitted for that purpose. Brown pyrometers are provided to indicate exhaust temperatures.

Although the operation of the Diesel engines will undoubtedly affect the heat balance of the Macy power plant profoundly, it at the same time provides a valuable security element, in so far as the Diesel engines can keep power on the switchboard without any assistance from the steam installation. Cooling water is the only service requiring energy, and that comes from the city mains, which, as has already been indicated, can be supplied to the Diesel engines without dependence on any other apparatus.

In plotting the estimated Diesel load curve on Fig. 4 it was borne in mind that at times of low load or no load on the air-conditioning refrigerating system considerable water might have to be drawn from the city mains to cool the Diesel engines, and that this might at times be a limiting factor for the percentage of output to be generated by them. At the same time it might happen that at periods of diminished activity by the air-conditioning plant the temperature of the water discharged from the condensers into the Diesel engines might be considerably lower, so that the smaller quantity might be offset by the removal of a greater number of heat units per pound of water within the permissible temperature rise set for the Diesel engines. However, if all the cooling water circulated through the jackets were to be charged for it would scarcely exceed $5500 per year, a sum which would amount to about 1 mill for each of the $5\frac{1}{2}$ million kw-hr. assumed to be generated.

A very general indication of what the cost of Diesel power in the Macy plant may be is given herewith on the assumption that $5\frac{1}{2}$ million kw-hr. will be generated at a yearly load factor of 48.3 per cent and that the annual labor charges assessed against the plant will be $7500.

THE DIESEL POWER PLANT

The Diesel engines selected for the plant consist of two Fulton Iron Works Co., 1000-b.hp., 8-cylinder, trunk-piston, 4-cycle, air-injection units direct-connected to two Crocker-Wheeler, 800-kw., 40 deg. cent., 250-volt, d-c. generators. Bore and stroke dimensions of the Diesel engines are $17\frac{1}{2}$ in. by $24\frac{1}{2}$ in. and their normal speed is 225 r.p.m. Under these conditions the brake mean effective pressure is 74.2 lb. per sq. in. and the piston speed 919 ft. per min. Force-feed lubrication is supplied to all the major bearings by means of a rotary pump integral with the engine, while an oil cooler and a Sharples centrifuge are provided for conditioning the oil. Lubrication of such parts as the cams and camshaft bearings as well as the timing gears has also been made automatic, so that practically no manual oiling service will be required anywhere on the engine. Lubrication of the engine and compressor cylinders is supplied by a Manzel lubricator with 19 feeds. Two Double Seal rings are fitted to each piston.

Compressed air for starting and injection of fuel is provided by three-stage compressors built integral with the engines. Each stage is provided with tubular intercooler separately supplied with cold water from the city mains.

The design of the engine had a direct bearing on its selection for installation in the limited space (Fig. 5) available and in the power plant of a store where customer comfort is elaborately catered to. The eight-cylinder arrangement permitted the attainment of maximum capacity in the relatively long and narrow Diesel engine room, while the inherently good-running balance of the units is a factor in reducing vibrations to a desirable point. Further assurance against undesirable vibration is seen in the frame construction of the units, which comprises a deep box-girder running from the surface of the bedplate to the underside of the cylinder heads. The frame is divided into cells by transverse webs between adjacent cylinders. Into each one is inserted a separate cylinder liner, the space between the liner and the cell wall serving as a water jacket. With the relatively large weight of the engine about 188,000 lb. the secondary dynamic forces due to inertia of the reciprocating parts becomes a negligible percentage of the total mass in which vibrations might be set up.

Installation of the engines in the small available head-room required the removal of considerable quantities of rock in order to provide for the foundation and for space in which to withdraw the pistons and connecting rods under the I-beams of the floor above. According to usual practice the foundation was not allowed to contact with the building structure at any point, a layer of Korfund natural-cork blocks having been laid down before the concrete for the foundation was poured. Cork was also used at the sides of the foundation, while the latter was loaded with heavy steel sections embedded near the bottom.

Air is to be drawn into the engines through Maxim silencers and Midwest viscous-baffle air filters directly from the engine room, which otherwise might become overheated due to the proximity of the steam engines. Each air-intake pipe is also provided with an electrically controlled emergency-stop valve which permits of shutting down the engines quickly under abnormal conditions.

Exhaust lines of ample size are connected to the engines and lead to Maxim silencers at the west end of the Diesel engine compartment. In order to avoid the transmission of possible vibrations to the building, interlocking flexible metallic tubing has been inserted between the engines and the exhaust lines, the longer one of which, leading from the east engine, consists of 12-in. pipe and the shorter one of 10-in. pipe. From the silencers, 16-in. piping leads to the main stack of the plant, the diameter of which is 11 ft. and which rises to a height of more than 300 ft. Under present conditions of operation the stack shows a considerable draft, amounting to some 3 or 4 in. of water.

Daily supply tanks for fuel are located high in the engine room to permit the fuel to flow under a slight head to the fuel pump on each engine. Each of the tanks is kept filled by a small rotary pump discharging at a constant rate through Bowser meters and an air-eliminating tank. The capacity of both the fuel transfer pumps and the meters have been proportioned so that whenever the meter is in action it will be working at near its normal capacity. This feature, and the provision for eliminating air, should assure accurate measurement of the fuel oil used.

A separate switchboard is being installed for the Diesel generating sets at the east end of the compartment. It is connected through heavy copper busses directly to the main switchboard of the plant and is equipped with massive circuit breakers of 6000 amp. capacity.

The d-c. direct-connected generators are provided with interpoles and are of massive construction. Their capacity, 800 kw. each, is larger than would ordinarily be provided for engines of 1000 b.hp., but provisions have been made for later supercharging the Diesel engines up to 1250 b.hp. each and for utilizing the full capacity of the generators in this manner. In the present analysis no consideration has been given to this proposal, because it will probably be possible to do this more satisfactorily after the Diesel engines have been in operation without supercharging and after suitable operating data have been recorded.

Acknowledgments for much of the information contained in this paper are made to Messrs. Cogan, Brennan, Harrigan, and Coghlan of the executive and operating staff at Macy's, and to the consulting engineering firms of Kaiser, Muller & Davies and Werner Nygren, Inc.

Discussion

EDGAR J. KATES.[2] According to the records only 20 per cent to 40 per cent of the steam-engine exhaust in this plant has been utilized throughout the year, prior to the installation of the Diesel engines. This is worthy of note because the *predicted* utilization of exhaust steam in plants of this kind is often assumed at a much larger ratio. The error in such predictions is that they fail to take account of the lack of coincidence between the demands for electric current and steam heat. Studies of power and heat requirements with a view to utilizing the maximum quantity of exhaust steam are too often based upon the *average* power and heat loads for daily, weekly, or monthly periods. Such studies lead to false conclusions because the utilization of the exhaust depends upon the transient relations between the power and heat loads, not upon averages. To be accurate, heat-balance studies must be made in great detail, using power and heat-load curves for all hours of the day and for all times of the year.

The small utilization of exhaust steam in the Macy plant is particularly significant when it is noted that unusual measures have been taken in this plant to utilize it. Low-pressure turbines have been installed to take the Corliss-engine exhaust, and the turbines discharge to condensers cooled by metered city water at considerable expense. These turbines operate an air-conditioning plant in the summer, and thus serve to increase the summer demand for low-pressure steam. Few power plants in city buildings have been elaborated to this extent, and generally their utilization of exhaust steam is still less than in the Macy plant. In such plants the addition of Diesel engines would accomplish even more than at Macy's.

In considering the broad problem of power and heat balancing by means of Diesel engines, it is well to remember that in the case of the Macy installation the Diesel engines were added to a full-size steam power plant that was already in operation. If the project had been that of an entirely new power plant where the designer had full choice as regards both the steam and Diesel equipment, an entirely different set-up would no doubt have ensued. In all probability the steam plant would have been made as simple as possible, the low-pressure steam turbines would have been omitted, and a larger proportion of Diesel power would have been installed.

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[2] Consulting Engineer, New York, N. Y.

OGP-52-14

Pressure Fluctuations in a Common-Rail Fuel-Injection System

By A. M. ROTHROCK,[1] LANGLEY FIELD, VA.

The instantaneous pressures at the discharge orifice of a common-rail fuel-injection system were determined by analyzing the stem-lift records of an automatic injection valve. The fuel injection was obtained by releasing fuel under high pressure from a reservoir by means of a cam-operated timing valve. The period of injection was controlled by the opening of a second cam-operated valve which reduced the fuel pressure between the timing valve and the injection valve to atmospheric pressure. The results show that pressure-wave phenomena occur between the high-pressure reservoir and the injection valve, but that these pressure waves can be controlled in a manner advantageous to the injection of the fuel. The results also give data as to the design of such an injection system for a high-speed fuel-injection engine. An injection system of this type insures the same rate of fuel discharge regardless of engine speed.

THE quantity of fuel delivered by a common-rail fuel-injection system is controlled either by the lift of a mechanically operated fuel-injection valve or by the time during which the oil in a high-pressure reservoir is released to an injection valve. The first type has not proved particularly successful with high-speed engines because of the difficulty of controlling the rate of fuel flow by controlling the lift of a mechanically operated valve. With the second system it is necessary to have one or two mechanically operated valves in conjunction with either an automatic injection valve or an open nozzle.

When one mechanically operated valve is employed, the fuel under pressure is released to the injection valve for a time interval equal to the time during which the mechanically operated valve remains opened. When this valve closes, the fuel continues to discharge until the oil between the mechanically operated valve and the injection valve drops to a pressure less than the injection-valve-opening pressure or to the pressure in the combustion chamber if an open nozzle is used. This results in a comparatively slow cut-off of the fuel spray. If, however, an automatic injection valve is used and a second mechanically operated valve is employed, which causes the stopping of fuel discharge by releasing the pressure between the high-pressure reservoir and the injection valve to some value less than the valve-opening pressure, a sharp cut-off of the fuel spray is assured. Such a fuel-injection system has the following characteristics:

1 Constant time for a given fuel quantity to be discharged regardless of engine speed
2 Sharp start of fuel spray
3 Sharp cut-off of fuel spray
4 Constant fuel dispersion and penetration regardless of engine speed, unless a cylinder head giving a high degree of turbulence varying with engine speed is employed.

In order to control the injection of the fuel into the combustion chamber of the engine, it is necessary to know the pressure variations at the discharge orifice as well as the time of injection and the static pressure in the high-pressure reservoir. These pressure variations are controlled by the design of the fuel-injection system and the physical properties of the fuel.

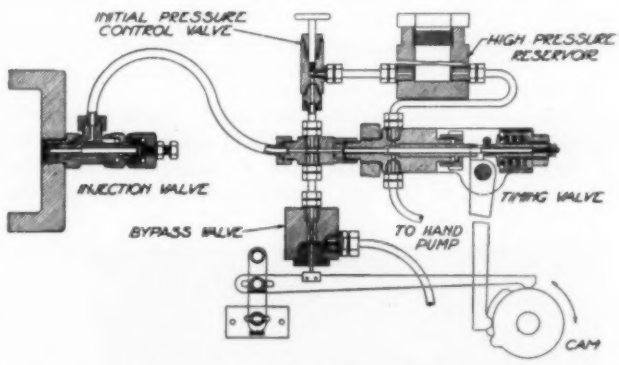


FIG. 1 FUEL-SPRAY-INJECTION SYSTEM

The system should be designed to meet these physical properties in such a manner that the instantaneous pressures at the discharge orifice cause the injection of the fuel according to the requirements of efficient combustion. Since fuel oils are compressible, they are subject to pressure-wave phenomena. To design a common-rail fuel-injection system with a definite rate of fuel discharge, the effect of the different parts of the injection system on the instantaneous pressures must first be determined. If these are known, the pressure fluctuations throughout the injection system and the rate at which the fuel is discharged can be varied almost at will.

The tests reported herein were conducted to determine experimentally the instantaneous pressures at the discharge orifice of a common-rail fuel-injection system in which the timing valve and cut-off valve were at some distance from the automatic fuel-injection valve, and also to determine the methods by which the pressure fluctuations could be controlled.

METHODS AND APPARATUS

The fuel-injection system of the N.A.C.A. spray photography equipment (Reference 1) was used for the investigation. It is illustrated diagrammatically in Fig. 1. The timing-valve cam was operated by a clutch which, when engaged, caused the cam to make one revolution. The cam speed for these tests was 1140 r.p.m., except where otherwise stated. As the timing-

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Presented at the National Oil and Gas Power Conference, State College, Pa., June 13 and 14, 1930.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

valve needle was lifted from the seat, the oil under pressure in the high-pressure reservoir was released through the injection-valve tube to the injection valve. The oil pressure acting on the annular area of the valve stem forced the steam from the seat, and the oil was sprayed into the chamber. The bypass

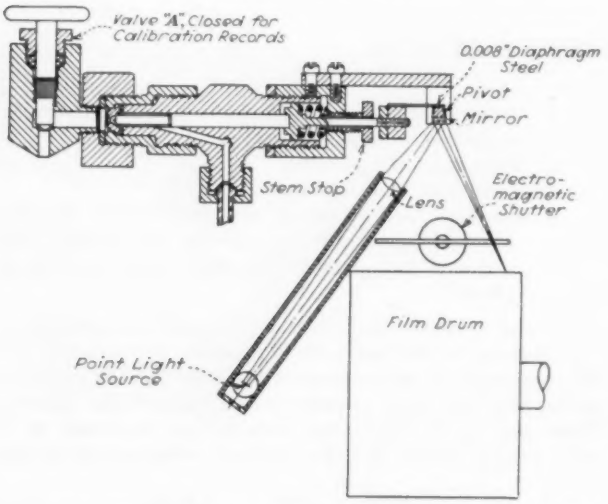
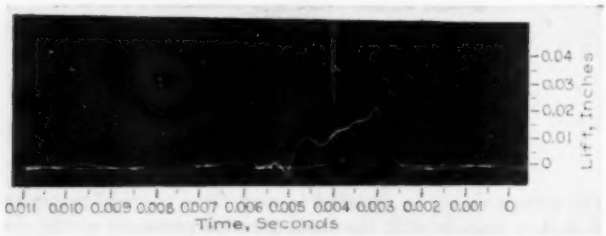


FIG. 2 AUTOMATIC INJECTION VALVE AND APPARATUS FOR RECORDING VALVE-STEM MOTION

or spray cut-off valve then opened; the hydraulic pressure in the injection-valve tube dropped due to the rapid flow of the oil through the bypass valve; and the injection-valve spring forced the stem to the seat, cutting off the fuel spray. The



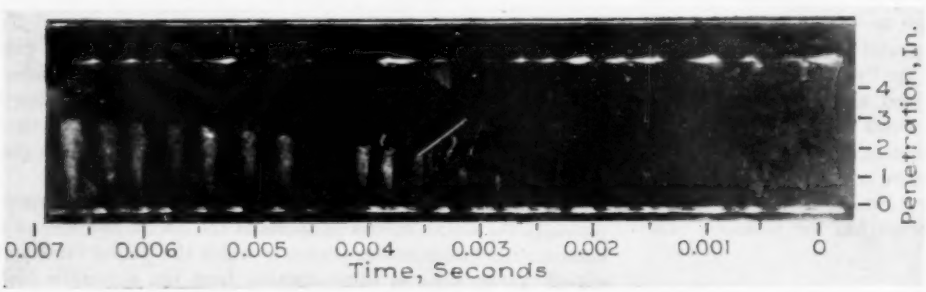


FIG. 3 FUEL-SPRAY DEVELOPMENT AND INJECTION-VALVE-STEM MOTION
(Upper chart, record of injection-valve-stem motion, with stem stop set at 0.021 in. Lower chart, fuel-spray photographs.)

time interval between the start of opening of the timing valve and bypass valve could be varied as shown in Fig. 1. For these tests the injection period was maintained at approximately 0.0045 sec. except where otherwise stated. The bypass valve was so adjusted that it opened before the timing valve started to close. The initial pressure in the injection-valve tube could be adjusted to any desired value by means of the initial-pressure-control valve. An initial pressure of 300 lb. per sq. in. was used in all these tests unless stated otherwise. The hydraulic pressures were obtained by a hand pump. The static pressures were indicated by a Bourdon spring gage mounted in the line between the hand pump and the high-pressure reservoir. Particular care was taken to remove all air from the injection system before each test was made.

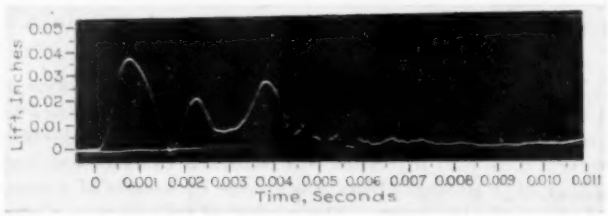


FIG. 4 RECORD OF INJECTION-VALVE-STEM MOTION, WITH NO STOP



FIG. 5 PRESSURE CALIBRATION RECORD

The injection valve shown in Fig. 1 was altered as shown in Fig. 2, so that the stem motion could be recorded. The record was obtained by directing a beam of light from a point source

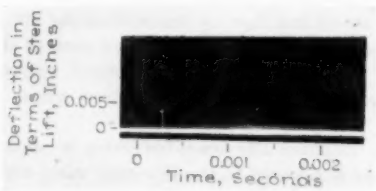


FIG. 6 RECORD OF VIBRATIONS CAUSED BY DIAPHRAGM STEEL LINKAGE

on the mirror operated by the valve stem and focusing the reflected beam on a film mounted on a revolving drum. The drum was driven by a synchronous motor at a peripheral speed of 1038 in. per sec. An electromagnetic shutter operated by the camshaft was placed in front of the film drum so that the beam of light fell on it for not more than three revolutions. This was done so that the line of zero lift would not appear as a heavy band. During the preliminary part of the investigation the injection valve was mounted in the spray chamber as shown in Fig. 1, and records were taken simultaneously of the injection-valve-stem motion and the development of the fuel spray. In order to synchronize the two records a small spark gap was placed in front of the stem-motion film. This gap was connected

in series with the main spark gap for taking the high-speed motion pictures of the fuel spray. Hence, for each spray photograph there appeared a small line on the stem-motion record. Fig. 3 shows records of the injection-valve stem and of the fuel spray taken in this manner. For this particular test the stem stop of the injection valve was set to limit the maximum lift to 0.021 in.

An examination of the chart shows that both the start of the spray and the start of the injection-valve-stem motion occurred between the seventh and eighth photographs and that spray cut-off came between the fifteenth and sixteenth photographs. The stem did not stay against the stop because of the pressure fluctuations. Since the two records taken simultaneously showed that the start and the stop of the spray followed the start and the stop of the injection-valve-stem motion within a few hundred-thousandths of a second, that is, within the accuracy of the experimental data, spray records were not taken for the majority of the tests, and the injection valve was mounted in the special holder shown in Fig. 2 so that calibration records could be taken after each stem-lift diagram.

All of the injection-valve records for the pressure analysis were taken with the stem stop backed off so that the stem did not strike it, in order that the stem motion could be used as the instantaneous-pressure indicator. A typical record is shown in Fig. 4. It is seen that the stem came in contact with the seat after the first oscillation, but did not touch it again until spray cut-off. It then struck the seat and made a series of short bounces. These bounces are the cause of the secondary discharges discussed by Beardsley in his tests on the causes of secondary discharges (Reference 2). They occur when the pressure in the injection-valve tube is still great enough during the bouncing of the stem to cause discharge.

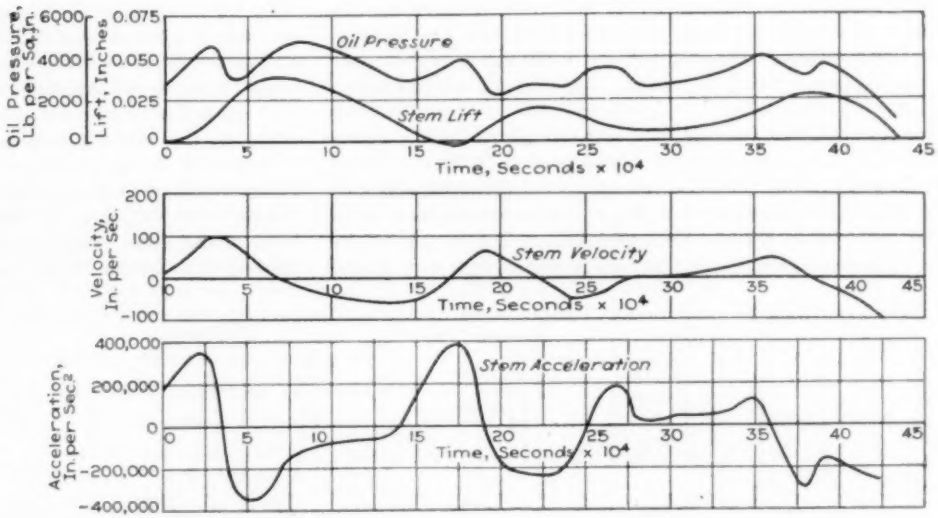


FIG. 7 STEM-LIFT RECORD SHOWN IN FIG. 4 PLOTTED TOGETHER WITH STEM-VELOCITY AND ACCELERATION CURVES AND PRESSURES AT DISCHARGE ORIFICE

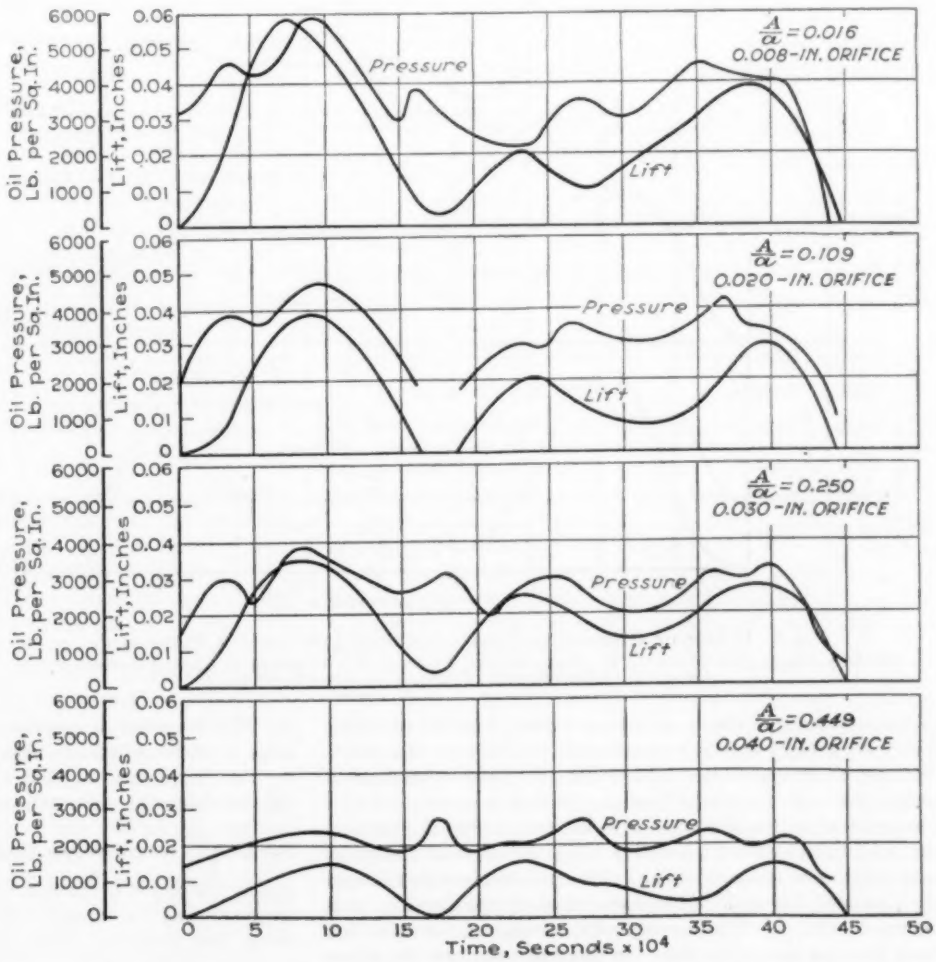


FIG. 8 EFFECT OF ORIFICE DIAMETER ON STEM LIFT AND OIL PRESSURE
(Injection pressure, 3500 lb. per sq. in.; valve-opening pressure, 2500 lb. per sq. in.; initial pressure, 300 lb. per sq. in.; tube length, 13 in.)

The calibration of the spring in the injection valve was obtained by closing the valve A shown in Fig. 2. The stem-recording mechanism was removed, and a dial indicator graduated in thousandths of an inch was placed against the spring follower of the injection valve. The hydraulic pressure was built up in stages of 500 lb. per sq. in., and the lift readings were recorded. From these data the spring scale of 3600 lb. per sq. in. was computed. The calibration of the lift as recorded on the film was obtained by replacing the lift-recording mechanism and building up the pressures in stages of 500 lb. per sq. in. At each pressure increment the point source light was flashed on for an instant so that a record was obtained on the revolving film with straight lines representing the lift for each increment. This record was converted into actual lift of the valve stem in inches from the spring calibration. It was necessary to take film calibration records after each lift record for, in changing the conditions between successive tests, the angle of the point source light was changed and any difference in this angle changed the recorded lift scale. The calibration record for Fig. 4 is shown in Fig. 5. The corresponding pressures for each line have been marked on the film. In this particular case the valve-opening pressure was 2500 lb. per sq. in.; consequently, there was no lift recorded until the pressure reached 2500 lb. per sq. in.

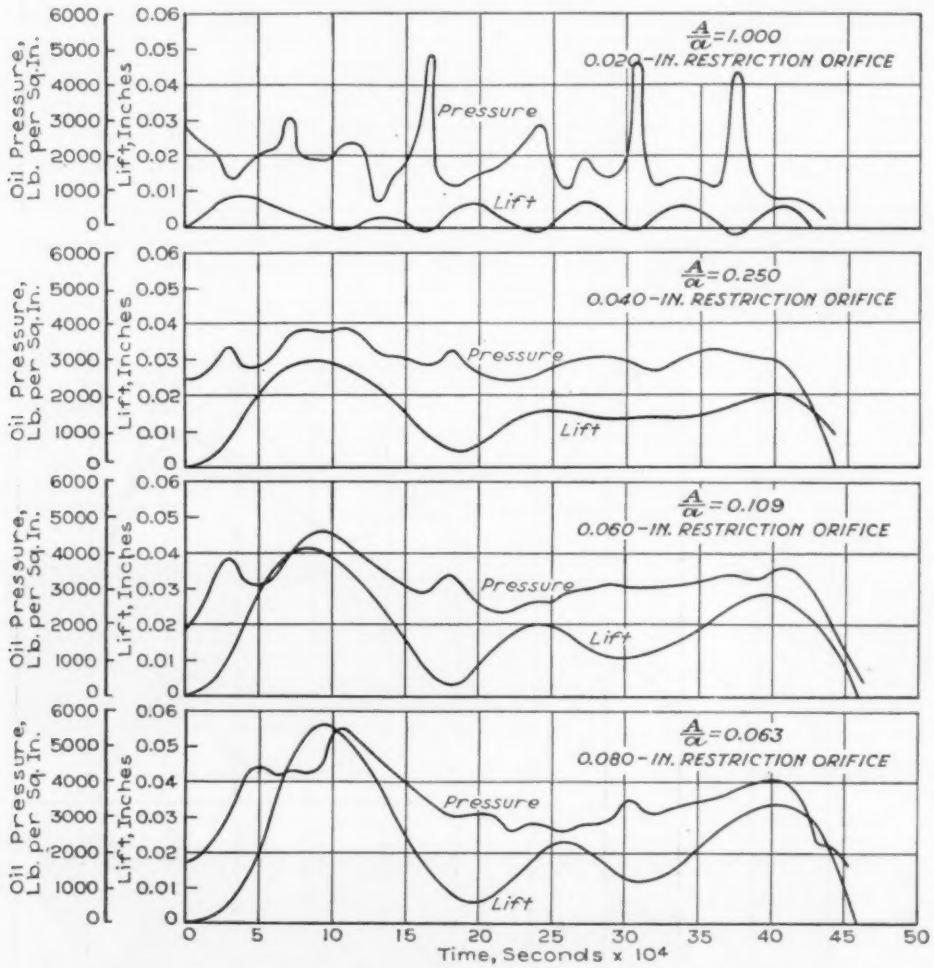


FIG. 9 EFFECT OF RESTRICTION ORIFICES ON STEM LIFT AND OIL PRESSURES
(Injection pressure, 3500 lb. per sq. in.; valve-opening pressure, 2500 lb. per sq. in.; initial pressure, 300 lb. per sq. in.; orifice diameter, 0.020 in.; tube length, 13 in.)

In order to obtain the frequency of the diaphragm steel linkage the diaphragm was deflected slightly and then released, and at the same time a photographic record was taken of the vibration of the reflected-light beam. The record, Fig. 6, shows that the period of vibration was too small to have any material effect on the stem-lift records.

Derivation of the Instantaneous Pressures at the Discharge Orifice From the Stem-Lift Records. At every instant the hydraulic force on the valve stem was opposed by the resisting force of the valve spring plus the product of the mass of the moving parts by the acceleration at that instant plus or minus the friction of the stem in its guide. For the valve with which these tests were made the friction force was negligible in comparison with the other forces and was consequently neglected. The force-equilibrium equation is therefore:

$$f = \lambda s + ma \ldots . [1]$$

in which f is the hydraulic force at any time t, λ the spring scale, s the compression of the valve spring at the time t, m the mass of the moving parts 0.069 lb. for the valve tested, and a the acceleration of the stem at the time t. The spring compression at any instant was the sum of the initial compression of the spring, obtained from the calibration record, plus the stem lift at the instant under consideration, obtained from the stem-lift record. The acceleration at any instant was obtained by first drawing the time-velocity curve from the tangents to the time-lift curve taken at 0.0001-sec. intervals and then drawing the time-acceleration curve from the tangents of the velocity curve taken at 0.0001-sec. intervals. The mean pressure on the stem was the total force divided by the area of the stem, 0.0398 sq. in. Fig. 7 shows the velocity, acceleration, and pressure curves, together with the lift curve for the experimental record shown in Fig. 4. The bouncing of the stem after cut-off is omitted. The stem oscillations indicate that the stem motion was controlled by two harmonics imposed upon each other. The first was the fundamental harmonic of the valve spring. Its period was $2\pi\sqrt{\frac{m}{\lambda}}$ which for the spring used was 0.0014 sec., approximately the period of the first oscillation, 0.0018 sec. The second harmonic was the fundamental harmonic of the oil column between the discharge orifice and the high-pressure reservoir. Its period was $2\pi l\sqrt{\frac{\rho}{2Eg}}$ in which l is the length of the oil column

between the discharge orifice and the high-pressure reservoir, 26.7 in. for the 13-in. tube, ρ the density of the Diesel oil, 53 lb. per cu. ft., E the modulus of elasticity of the oil, 284,000 lb. per sq. in. (Reference 3), and g the gravitational constant. Substituting these values in the expression gives a value of 0.0020 sec. The actual period as obtained from the chart is 0.0026 sec. The difference between the actual period and the theoretical period can be accounted for in part by the fact that the value of E has not been accurately determined, but chosen from the values of other oils of similar properties. The curves show in nearly all cases a sharp drop in pressure after about the first 0.0004 sec. caused by the start of the discharge from the orifice. There is a sharp build-up of pressure due to the restriction to oil flow whenever the stem reaches or nearly reaches the seat during its oscillations.

The flow of oil through the discharge orifice was computed from the pressure curves and the conventional flow formula $Q = AVt$ in which $V = C\sqrt{2gh}$. The pressure for computing the total discharge was taken as the square of the mean of the square roots of the instantaneous pressures. Coefficient of discharge tests made on the 0.008- and 0.020-inch orifice with the apparatus employed by Joachim (Reference 3) showed that the coefficients of discharge of these orifices over the range of pressures investigated did not vary materially from 0.94. The actual discharges were obtained by screwing a small container on the injection valve and weighing ten injections. In every

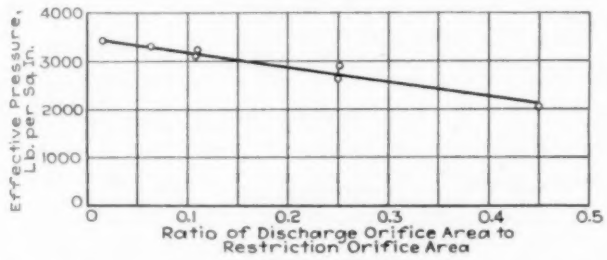


FIG. 10 EFFECT OF RATIO OF DISCHARGE-ORIFICE AREA TO RESTRICTION-ORIFICE AREA ON EFFECTIVE PRESSURE

case two or three sets of ten discharges were weighed and the mean was taken. In no case did the individual weights vary by more than 3 per cent from the mean.

TEST RESULTS

Effect of the Ratio of Discharge-Orifice Area to Area of Smallest Restriction Between the High-Pressure Reservoir and Discharge Orifice. The tube connecting the high-pressure reservoir with the timing valve had an internal diameter of 0.063 in. The diameter of the passage connecting the timing valve to the injection valve tube was 0.094 in. The injection tube was made of seamless steel tubing with an outside diameter of 0.250 in. and an inside diameter of 0.125 in. The oil passage in the injection valve between the injection-valve-tube connection and the passage around the valve stem had a diameter of 0.094 in. Consequently, the smallest restriction was the 0.063-in. tube between the high-pressure reservoir and the timing valve. Two series of tests were conducted to determine the effect of the ratio of the discharge-orifice area to the area of the smallest restriction in the line. In the first series the stem lift was determined for different diameter discharge orifices. In the second series the stem lift was determined with a constant discharge orifice diameter, but with various restriction orifices inserted in the injection line at the entrance to the automatic injection valve.

The effect of varying the discharge-orifice diameter is shown in Fig. 8. The ratio of the discharge-orifice area to the restriction area is symbolized by A/a. As the ratio was increased more of the energy of the initial-pressure wave was expanded in discharging the fuel oil and less of it was utilized in a wave reflected back to the high-pressure reservoir. Consequently, the intensity of the pressure waves and the stem lift decreased as the orifice diameter increased. Between the ratio of 0.25 and 0.45 there comes a point where the wave energy was almost entirely transformed into the kinetic energy of the discharging oil and the pressures at the discharge orifice remained virtually

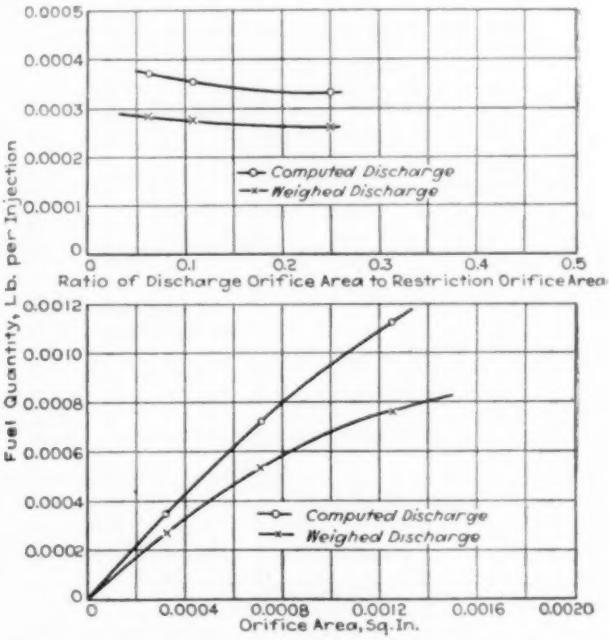


FIG. 11 EFFECT OF RESTRICTION-ORIFICE AREA AND DISCHARGE-ORIFICE AREA ON FUEL QUANTITY DISCHARGED

constant, although the stem oscillated, opening and closing the valve.

Fig. 9 shows the effect of the ratio when the discharge orifice remained constant and the diameter of the restriction orifice was varied. The same phenomenon occurred as is shown in Fig. 8. The important fact to notice in these two figures is the similarity of the curves for the same ratios. For the 0.020-in. restriction orifice with a ratio of 1.0 the valve stem oscillated to a greater extent than with the ratio of 0.45. Although the values given for the instantaneous pressures in this particular case are open to question, because of the difficulty of analyzing the curve at the line of zero lift, the curve does show that there were violent fluctuations of pressure because of the rapid opening and closing of the valve.

The effect of the ratio of the discharge-orifice area to the restriction-orifice area on the effective pressures is shown in Fig. 10. As the ratio decreased, the effective pressure approached the static pressure in the high-pressure reservoir. The difference between the static pressure and the effective pressure was directly proportional to the ratio. Since the effective pressure decreased as the orifice area was increased, the quantity of fuel discharge (Fig. 11) did not vary directly with the orifice area. Both the computed and actual discharge curves follow the same general trend. The discrepancy between the two is due to the losses in weighing the fuel, to the restriction to flow when the valve stem approached the seat, and probably because the mean pressure across the stem was somewhat greater than

the mean pressure across the discharge orifice. In Fig. 11 it also is seen that as the ratio A/a increased, the fuel quantity discharged decreased.

It can be concluded from the charts that, for an injection system of this type, the ratio of the discharge-orifice area to the area of the smallest restriction in the fuel line should not be greater than 0.25.

Effects of Injection-Valve-Tube Length. The effects of the injection-valve-tube length on the stem life and pressure variations are shown in Fig. 12. As the length of the injection-valve tube is increased, the period of vibration of the oil column is increased. The computed periods for the tube lengths are 0.0020 sec. for the 13-in. tube, 0.0028 sec. for the 24-in. tube, 0.0038 sec. for the 37-in. tube, and 0.0063 sec. for the 70-in. tube. Consequently, the 13-in. tube is the only one which permits two maximum pressures to be reached in the injection period. With the 24-in. tube the pressure reaches a minimum and has started to increase when cut-off occurs. With the 37-in. tube cut-off occurs when the pressure has reached a minimum. The 70-in. tube gives virtually a constant pressure during the whole injection period, since the initial wave has just started to decrease at cut-off. As the tube length was increased, the pressure and the lift at the point of cut-off decreased, the bouncing of the stem after cut-off decreased, and with it the tendency for secondary discharges. From these curves and the work of Beardsley (Reference 2), it can be concluded that secondary discharges will occur when spray cut-off occurs during the peak of a pressure wave. These curves also substantiate Beardsley's results (Reference 2), which showed that the spray penetration was slightly increased with an increase in tube length. The penetration of the spray is caused chiefly by the maximum pressure of the initial wave, but is aided to some extent by the pressures which follow this maximum. An examination of the chart shows that the maximum pressures for the 13-, 24-, and 37-in. tubes were very nearly the same. However, as the tube length was increased, the rate of pressure drop after the maximum was reached became less, and the resultant penetration was therefore greater. With the 70-in. tube the maximum pressure was less than with the other tubes, but the pressure remained at this maximum value for a considerable time. The curves show that to obtain a high constant pressure with an injection system of this type the period of injection should be one-half the period of the pressure waves in the injection-valve tube. Stated in another way, the length of the injection tube in inches should be twice the injection period in ten-thousandths of a second.

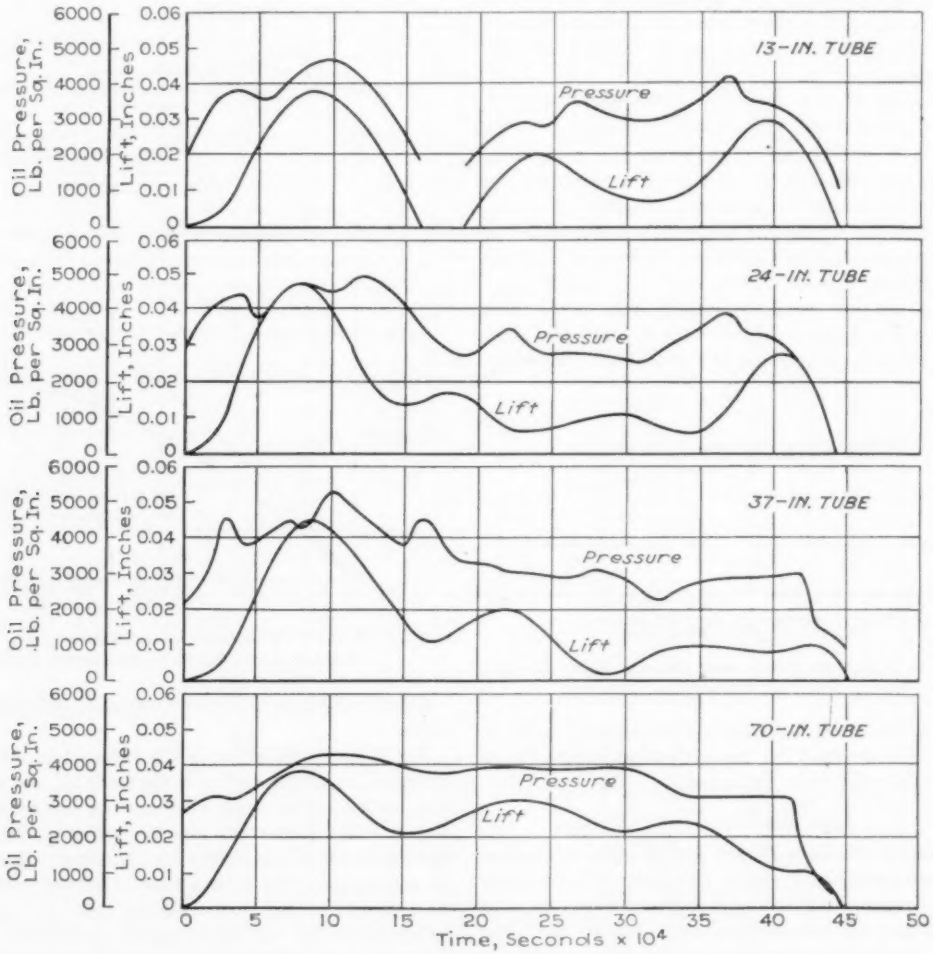


FIG. 12 EFFECT OF TUBE LENGTH ON STEM LIFT AND OIL PRESSURE
(Orifice diameter, 0.020 in.; injection pressure, 3500 lb. per sq. in.; initial pressure, 300 lb. per sq. in.; valve-opening pressure, 2500 lb. per sq. in.)

The effects of the tube length on the effective pressure and fuel quantities discharged are shown in Fig. 13. As Fig. 10 indicates, the effective pressure increases with tube length until

with the 70-in. tube the effective pressure is virtually the static injection pressure. The curves for the weight of oil discharged show that the weight of fuel discharged increases as the tube length is increased. It is interesting to note that with the 70-in. tube in which the pressure remained virtually constant there is considerably less deviation between the computed discharge and the actual discharge. This indicates that the oil flow did not follow the rapid fluctuations in pressure which occurred with the shorter tubes.

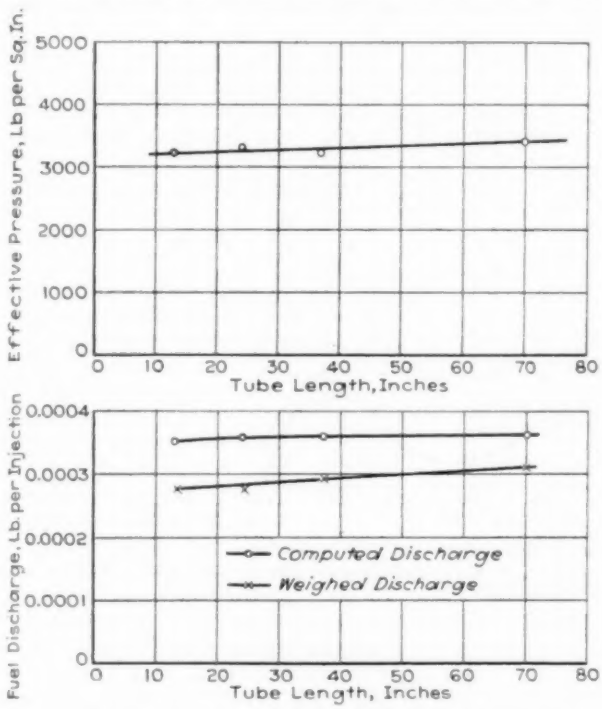


Fig. 13 Effect of Tube Length on Effective Pressure and Fuel Discharged

Effect of Timing-Valve Camshaft Speed and Injection Period. The effect of the timing-valve camshaft speed and the injection period on the pressure fluctuations is shown in Fig. 14. As the timing-valve camshaft speed was decreased, the maximum pressure reached on the first and second waves decreased slightly. The pressure wave was damped out before the third oscillation, so that for the lowest r.p.m. the pressure after the first 0.0045 sec. remained virtually constant at the static injection pressure. Fig. 15 shows the effect of the camshaft speed and injection period on the effective pressure and the fuel quantity discharged. It is seen that the effective pressure dropped from 3300 lb. per sq. in. at 1140 r.p.m. to 3150 lb. per sq. in. at 480 r.p.m. Since the rate of fuel discharge varies as the square root of the pressure, the mean rate of discharge at 480 r.p.m. is only 2 per cent less than at 1140 r.p.m. It can be concluded from these curves that for an injection system of this type the fuel-spray penetration and distribution, except for the effect of air turbulence, and the time for delivering a given fuel quantity are independent of engine speed.

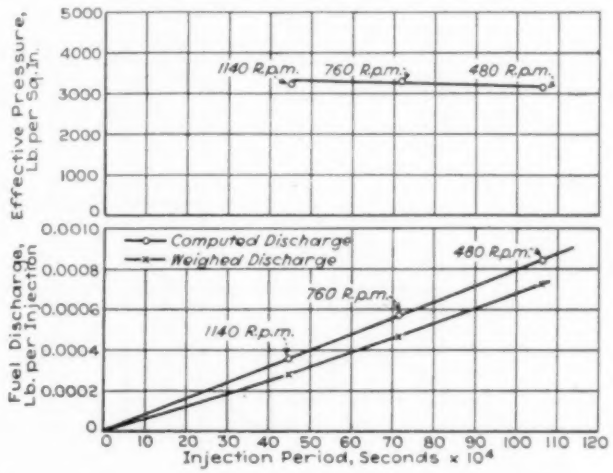


Fig. 15 Effect of Timing-Valve-Cam Speed and Injection Period on Effective Pressure and on Fuel Discharged

Effect of High-Pressure Reservoir Volume. An important factor in the design of a common-rail fuel-injection system is the volume of the high-pressure reservoir. The volume should be of sufficient size so that the pressure drop during injection is small, and at the same time the reservoir should be small enough to be in proportion to the rest of the engine. For the tests already presented the volume was 20 cu. in. A test was made with a 10-cu. in. reservoir. The results of this test in comparison to one with the 20-cu. in. reservoir are shown in Fig. 16. The stem-lift and pressure curves are virtually the same for the two reservoirs. Further research is necessary, however, to determine the minimum high-pressure reservoir

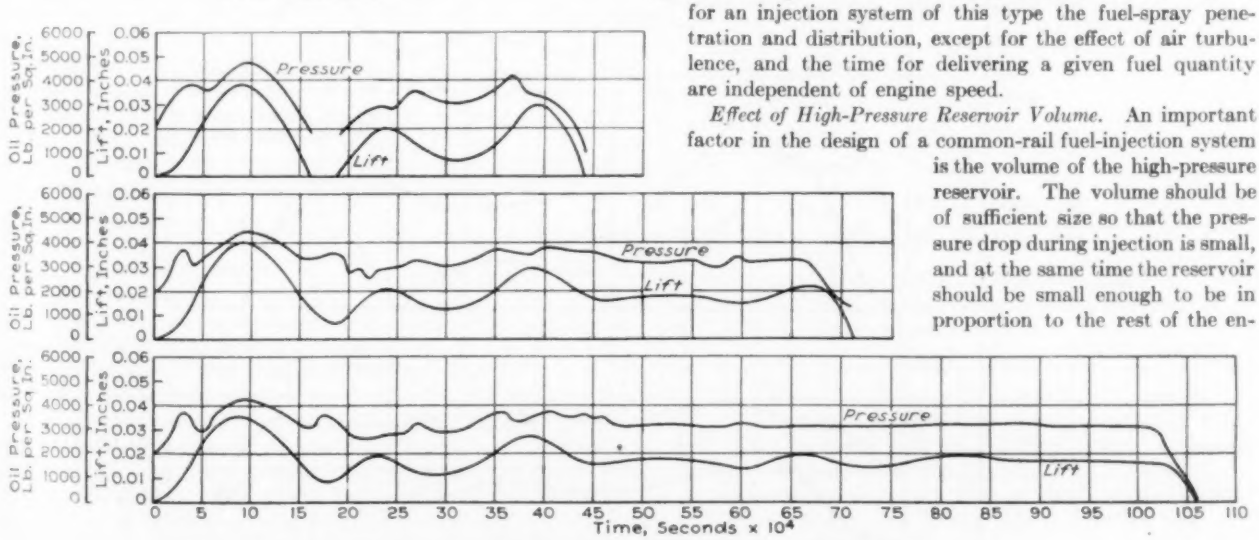


Fig. 14 Effect of Timing-Valve-Cam Speed on Stem Lift and Oil Pressure

(Injection pressure, 3500 lb. per sq. in.; initial pressure, 300 lb. per sq. in.; valve-opening pressure, 2500 lb. per sq. in.; tube length, 13 in.; orifice diameter, 0.020 in.)

volume that can be employed without affecting the pressures at the discharge orifice.

Effect of Initial Tube Pressure. The effect on the stem lift and the pressure variations of the initial pressure in the injection-valve tube before the opening of the timing valve is shown in Fig. 17. As the initial pressure was increased, the maximum pressure decreased, and the pressure curve changed from a wave form to a curve of almost constant pressure. There was, however, little change in the effective pressures, 3100 lb. per sq. in. for the 300 lb. per sq. in. initial pressure, 3300 lb. per sq. in. for the 1000 and 2500 lb. per sq. in. initial pressures. The total injection periods increased with the initial pressure. Therefore, since the setting of the bypass valve remained the same for all the tests, the time lag of injection decreased as the initial pressure increased. In the report on the time lags of injection (Reference 5) it was stated that the time lag was independent of the initial pressure providing the injection pressure was considerably in excess of the valve-opening pressure. The results presented here show that the time lag is dependent on the initial pressure when the valve-opening pressure is comparable to the injection pressure.

When there is an initial pressure in the injection-valve tube

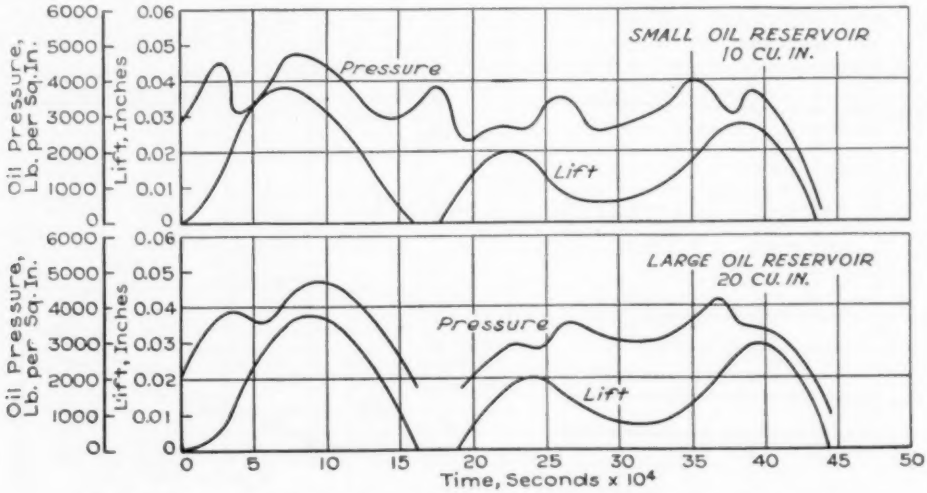


FIG. 16 EFFECT OF OIL-RESERVOIR VOLUME ON STEM LIFT AND OIL PRESSURE
(Injection pressure, 3500 lb. per sq. in.; initial pressure, 300 lb. per sq. in.; valve-opening pressure, 2500 lb. per sq. in.; orifice diameter, 0.020 in tube length, 13 in.)

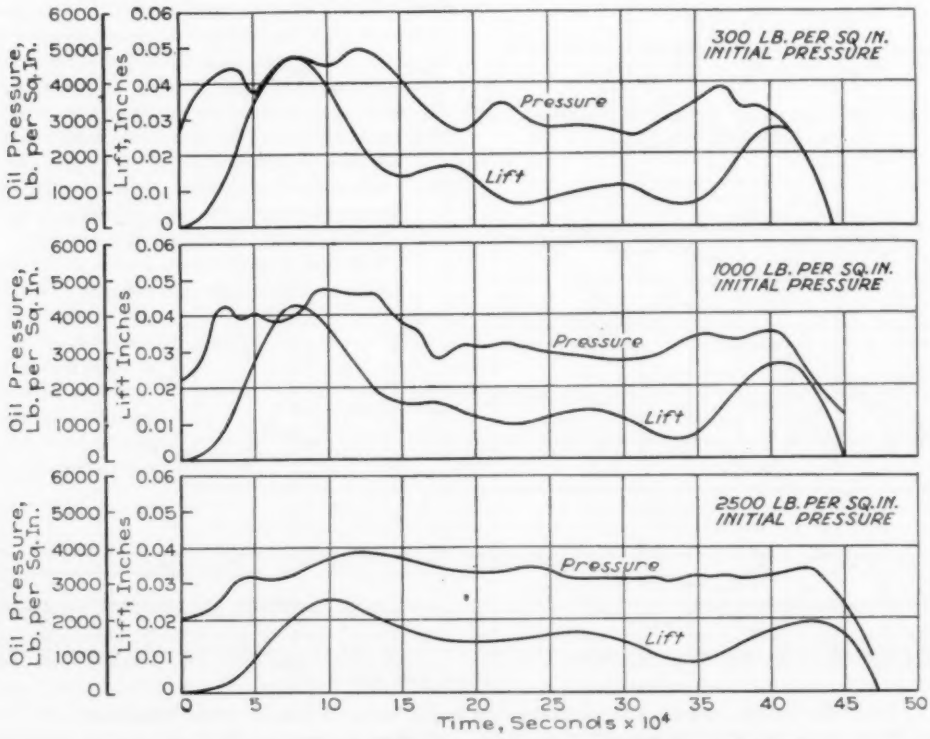


FIG. 17 EFFECT OF INITIAL PRESSURE ON STEM LIFT AND OIL PRESSURE
(Injection pressure, 3500 lb. per sq. in.; valve-opening pressure, 2500 lb. per sq. in.; tube length, 24 in.; orifice diameter, 0.020 in.)

preceding the opening of the timing valve, the same pressure must be left in the tube from the preceding injection. Consequently, the cut-off of the spray would not be as sharp as shown in the chart where the fuel pressure dropped to atmospheric. Beardsley (Reference 3) has shown that the spray penetration increases slightly with the initial pressure. The curves show that this is due to the slower rate of pressure drop after the first wave as the initial pressure increases. It can be concluded from the chart that a high initial pressure in the fuel-injection line does not present any advantages which cannot be obtained by lengthening the injection tube, but does cause a slow cut-off of the fuel spray.

Effect of Injection Pressure. Fig. 18 shows the effects of the injection pressure on the stem-lift and pressure variations. In the first example the injection pressure was less than the valve-opening pressure. However, the first wave from the reservoir built up to a pressure of 2400 lb. per sq. in. and consequently lifted the stem slightly. The valve then remained closed until the second wave reached it. The second wave was of slightly less intensity than the first, but was sufficient to again lift the stem. The period of this wave obtained from the chart was 0.0034 sec. The computed value is 0.0028 sec. With an injection pressure of 2500 lb. per sq. in., the valve opened four times during the injection period. With an injection pressure of 3500 lb. per sq. in., as has been shown before, the valve remained open during the whole injection period. When the injection pressure was further increased to 4000 lb. per sq. in., the pressure and stem-lift curves were of the same form as for the injection pressure of 3500 lb. per sq. in., but of greater intensity.

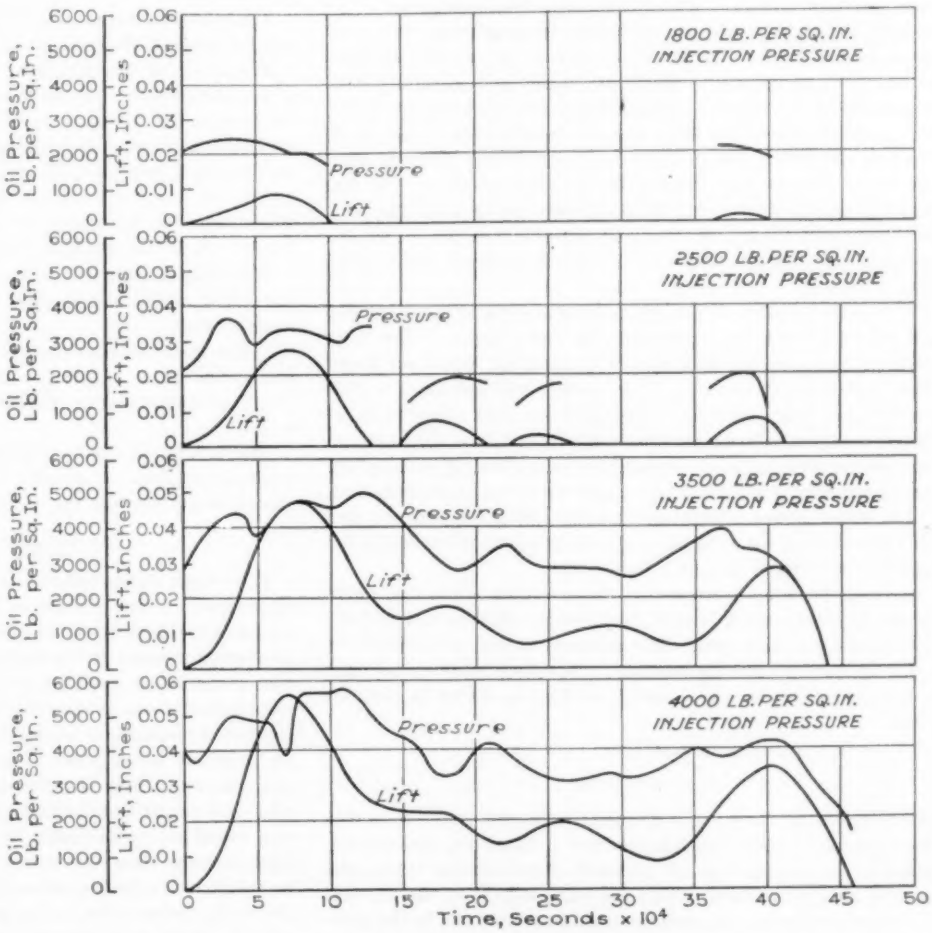


FIG. 18 EFFECT OF INJECTION PRESSURE ON STEM LIFT AND OIL PRESSURE
(Initial pressure, 300 lb. per sq. in.; valve-opening pressure, 2500 lb. per sq. in.; tube length, 24 in.; orifice diameter, 0.020 in.)

The injection pressure to be used in the design of an injection system of this type is based on the time required to get a given fuel quantity into the engine and the spray penetration and atomization desired. The curves show that unless the total hydraulic force on the stem after it is lifted is sufficiently greater than the spring force on the stem when the valve is closed the stem will not remain from the seat during the whole injection period.

CONCLUSIONS

There are two main conclusions to be drawn from these tests: First, with a common-rail fuel-injection system in which the source of high pressure is at some distance from the injection valve, pressure waves will occur at the injection valve. Second, these pressure waves can be controlled in a manner advantageous to the injection system.

Several conclusions can be drawn also as to the design of such an injection system. They are:

1 The injection tube connecting the high-pressure reservoir to the injection valve should have an area at least four times the sum of the area of the discharge orifice.

2 The injection tube connecting the high-pressure reservoir to the injection valve should have a length in inches equal to twice the injection period in ten-thousandths of a second.

3 The instantaneous injection pressures are virtually independent of engine speed, and the injection period in seconds for a given fuel quantity is independent of engine speed.

4 A high residual or initial pressure in the injection tube has no material advantages on the injection of the fuel.

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4 Joachin, W. F., "An Investigation of the Coefficient of Discharge of Liquids Through Small Round Orifices," N.A.C.A. Technical Report No. 224, 1926.

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Discussion

P. H. Schweitzer.[2] The writer gladly admits that he learned much from this paper.

In any experimental investigation of this nature the work of the investigator consists of two distinctly different functions: first, to find his data; second, to interpret what he found. The second is more important. One man obtains more useful information from a set of incomplete and inaccurate data than another man from the most complete series of accurate measurements. The making of the tests requires accuracy, thoroughness, and a respect for the facts. The interpretation of the results requires broad view, imagination, deductive logic, and generalization, frequently at the expense of apparently contradicting evidence. One does not often find these characteristics in the same man. Yet it is difficult to assign these functions to two different men, one to lay out the tests and another to interpret them. No one is as competent to interpret the test results as the man who lives and sleeps with them. No one is as competent to lay out experiments as the man who knows how he will interpret them when they are made.

The author displayed considerable skill both in carrying out and in interpreting the experiments on fuel injection. The tests made on pressure fluctuations are interesting, and their interpretations are still more so. The author realized that, at this early stage, when existing information on fuel injection is so scarce, it is better to squeeze the experimental data for practical information than to be too scrupulous by concluding nothing but the obvious from faultless and complete series of experiments.

The writer agrees completely with the author's procedure, and the requests that his comments on certain points discussed in the paper be considered in such a light.

It seems to be established that the bouncing of the fuel valve caused by inertia vibrations is chiefly responsible for the undesirable secondary discharges. The inference would be to make the valve needles as light as possible. But they have to be rigid at the same time, as was pointed out by the writer in his own paper.

In the force-equilibrium equation

$$f = \lambda s + ma \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

f is the hydraulic force and is divided by the area of the stem plus the hydraulic pressure which causes flow. However, the f so computed is the resultant of all hydraulic forces acting (1) on the annular area of the stem, (2) on the seat, and (3) on the tip, and it is equal neither to the pressure before the seat nor to the pressure behind the seat. To compute the discharges from these pressures as done in Fig. 11 is not fully justified. The discharge so calculated will be too small. The pressure drop past the seat is greater with large orifices than with small orifices; therefore the difference in the discharged fuel quantity should increase with the orifice area. That explains the "discrepancy" in Fig. 11 in the opinion of the writer.

The elastic compression of the valve stem was apparently not considered in the calculations. How much did that amount to in maximum?

That the same ratios of orifice area and restriction area produce similar pressure fluctuations is not evident from Figs. 8 and 9.

The effect of the injection tube length on the valve motion is most interesting. If the injection tube length is less in inches than twice the injection period in seconds, one is liable to get undesirable pressure fluctuations. But this cannot hold all the way through, because with very short tubes everything is correct again. It would be interesting to know when the very short tubes begin to misbehave and what small reservoir capacities close to the orifice might help in the injection.

While the investigation reported is very interesting and useful, the writer would like to have it supplemented with these two measurements:

1 The instantaneous pressures in the line taken with a pressure indicator.

2 The instantaneous discharges taken with a spray stroboscope.

The data so obtained would permit the checking of the author's conclusions, and, in combination with the valve-motion diagrams, would result in the drawing of more of them.

Author's Closure

The elastic compression of the injection-valve stem was not considered. Using a value of 30,000,000 lb. per sq. in. for the modulus of elasticity of the stem, and considering the maximum pressure increment on the stem, 4000 lb. per sq. in., the compression of the 2.5-in. stem is computed to be 0.0003 in. Since this compression does not take place instantaneously, its effect on the computed pressures is negligible. As Professor Schweitzer says, an infinitely short tube—that is, one of zero length—would again do away with the pressure waves, since the frequency of vibration would then be infinite. In this case the injection system would have a mechanically operated injection valve, and the high-pressure reservoir would be the controlling factor of the instantaneous injection pressures. In comparing Figs. 8 and 9, the author refers only to the general shape of the curves. The author agrees with Professor Schweitzer that a pressure indicator in the injection line would give interesting results and that measuring the rates of discharge with a spray stroboscope would also extend the scope of the work.

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[2] Associate Professor of Engineering Research, Pennsylvania State College Engineering Experimental Station, State College, Pa. Mem. A.S.M.E.

OGP-52-15

Factors in Diesel Spray-Nozzle Design in the Light of Recent Oil-Spray Research

By P. H. SCHWEITZER,[1] STATE COLLEGE, PA.



NOT every result of oil-spray research can readily be interpreted in terms of nozzle design, but many of them can. In the presence of a bewildering diversity in Diesel spray-nozzle constructions, theory and experimental research furnish some guides that it would be unwise to ignore in laying out spray nozzles.

A fuel-injection system is required to deliver definite amounts of liquid in sufficiently divided sprays of suitable geometrical shape into a number of cylinders accurately timed in relation to the engine cycle. Consequently, the spray nozzle has to perform or help to perform the following duties: (1) Metering, (2) timing, (3) injecting, and (4) spraying.

Metering

Theoretically the nozzle has little to do with metering except in constant-pressure or common-rail systems; practically, however, even with pump regulation the nozzle is a chief factor in metering.

For short orifices with a length up to, say, four times the diameter, the familiar formula[2] $v = c\sqrt{2gp/\rho}$ may be used, taking $c = 0.80$ when the edges, both ingoing and outgoing, are slightly chamfered. The discharge increases with the square root of the pressure and is independent of the viscosity. This means that, for heavy oil and light oil, the same orifice may be used and the discharge will be equal.

For very long orifices the Poiseuille formula should be used, $v = pgd^2/32\,l\eta$, according to which the discharge proportionally decreases when the viscosity of the liquid increases. Now the same nozzle orifice cannot be used for various oils. The heavy oil requires a wider orifice.

For medium long orifices, say 4 to 10 diameters, the square-root formula may be used with a viscosity correction $v = c'\sqrt{2gp/\rho}$, where $c' = \dfrac{1}{\sqrt{\dfrac{32\,l/d}{R} + 2m}}$. R is the Reynolds number; m is a constant with a value 0.5 — 1.12; 0.5 in the vicinity of the critical region.

A practical conclusion is to eliminate the use of nozzle orifices longer than four times the diameter. Then with a change of oil or a change of temperature it is unnecessary to change the orifice in order to get a similar discharge. The discharge of chamfered short orifices can be calculated with the formula $W = 0.80\,a\,2\sqrt{gp/\rho}$.

Another suggestion is not to use square-edged orifices, but always to give a slight chamfer to the edges. The author tried to use geometrical square-edged orifices in order to get reproducible results, but found that the discharge through square-edged orifices varied more than the discharge through chamfered orifices. Small differences in the angle and depth of the chamfer do not make as much difference as unavoidable burrs and irregularities in the square orifices. The author stopped using square-edged orifices even for scientific experiments. In production, a chamber of 0.004 to 0.005 in., at least, should be applied.

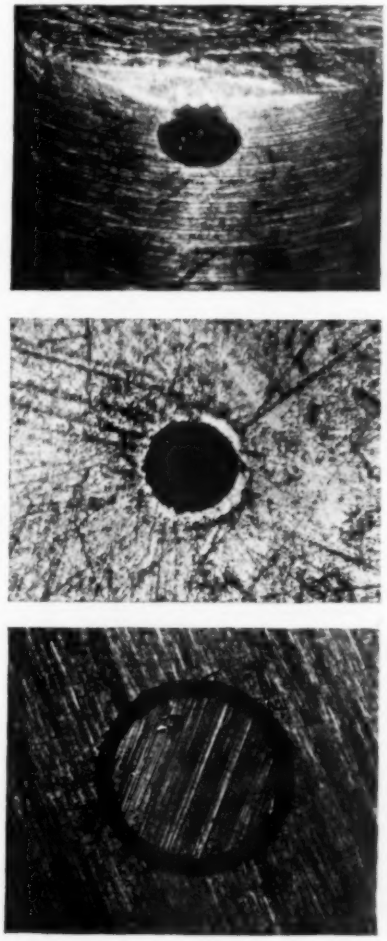


FIG. 1 THREE EXAMPLES OF COMMERCIAL SPRAY-NOZZLE ORIFICES × 24
(Top, poor; middle, fair; bottom, good.)

For determining the diameter of the orifice hole the most practical method is to use a low-power microscope. Every shop which has anything to do with Diesel nozzles should have a microscope of 20 to 30 magnification. With that, one cannot only quickly determine the diameter of the hole, but also can see how perfect the hole is. It is no exaggeration to state that a good part of the Diesel orifices in use should not be in use; they should have been rejected before the assembly, because the holes are crooked, out of round, or partly clogged with metal chips, etc. Fig. 1 shows three commercial orifices in 24 times magnification. An orifice such as the one at the top cannot produce a good spray. Poor workmanship and inadequate inspection of the nozzles are perhaps responsible for more unsatisfactory engine performance than poor nozzle design. The microscope is a good tool for the shop.

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[1] Associate Professor of Engineering Research, Pennsylvania State College. Mem. A.S.M.E. Dr. Schweitzer received the degree of Mechanical Engineer in 1917 from the Polytechnic Institute, Budapest, Hungary, and the degree of Doctor of Engineering from Polytechnic Institute, Dresden, Germany. In 1920 he came to this country and became engaged in commercial Diesel-engine development. Since 1923 he has been associated with the Pennsylvania State College, where he is in charge of the Diesel-engine laboratory and is at present conducting an investigation on oil sprays.

[2] NOTATIONS: v, jet velocity; c, coefficient of velocity; g, acceleration of gravity; p, pressure drop; ρ, specific gravity; d, orifice diameter; l, orifice length; η, kinematic viscosity; c', coefficient of velocity with viscosity correction; $R = dv/\eta$, Reynolds number; m, F. Hagenbach constant; W, volumetric discharge.

Presented at the Third National Oil and Gas Power Meeting, at State College, Pa., June 12–14, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Another good shop tool is a simple device shown by the sketch in Fig. 2. A target made of blotting paper with a 1-in. diameter hole in the middle is placed concentrically with and about 20 in. distant from the spray nozzle. One shot against such a target shows whether the nozzle shoots reasonably straight or is off.

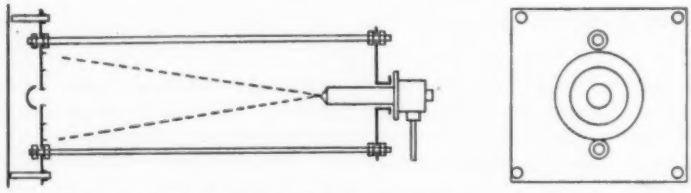


FIG. 2 SIMPLE DEVICE TO TEST CONCENTRICITY OF SPRAYS

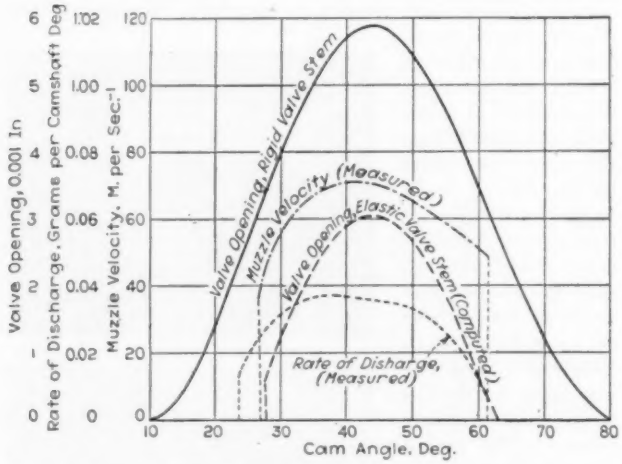


FIG. 3 VALVE LIFT, MUZZLE VELOCITY, AND RATE OF DISCHARGE
(The actual valve opening occurs later, the closing earlier, and the lift is smaller than that corresponding to the cam profile. The elasticity of the valve stem is responsible for the difference. Nozzle, 0.025 by 0.075 in.; speed, 131 r.p.m.; injection pressure, 3000 lb. per sq. in.; chamber pressure, at atmosphere; oil, Gulf heavy black.)

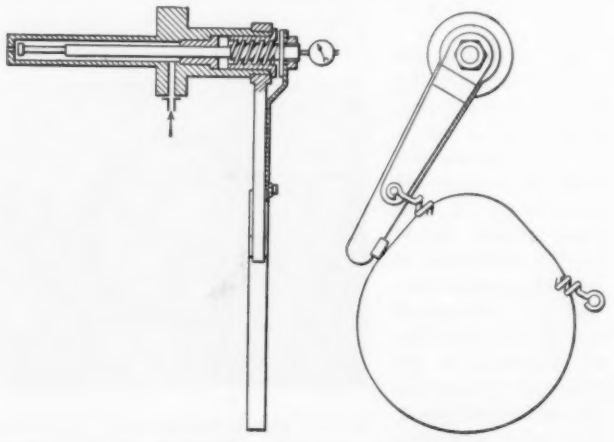


FIG. 4 SPRAY-VALVE MECHANISM

Every nozzle should be tested for concentricity before putting it into an engine, because defectives are very common.

The other factor in metering in a common-rail system is the time element, the opening period of the valve. This is closely related to the timing, and therefore it will be touched upon under that heading.

TIMING

Timing in a common-rail system is ordinarily effected by means of a mechanically operated admission valve actuated by a cam. If the follower follows the cam profile, it is usually assumed that the spray-needle tip follows it also. Therefore the valve opening, closing, and rate of injection are all determined by the cam profile. If anything is wrong with the timing, the first thing blamed

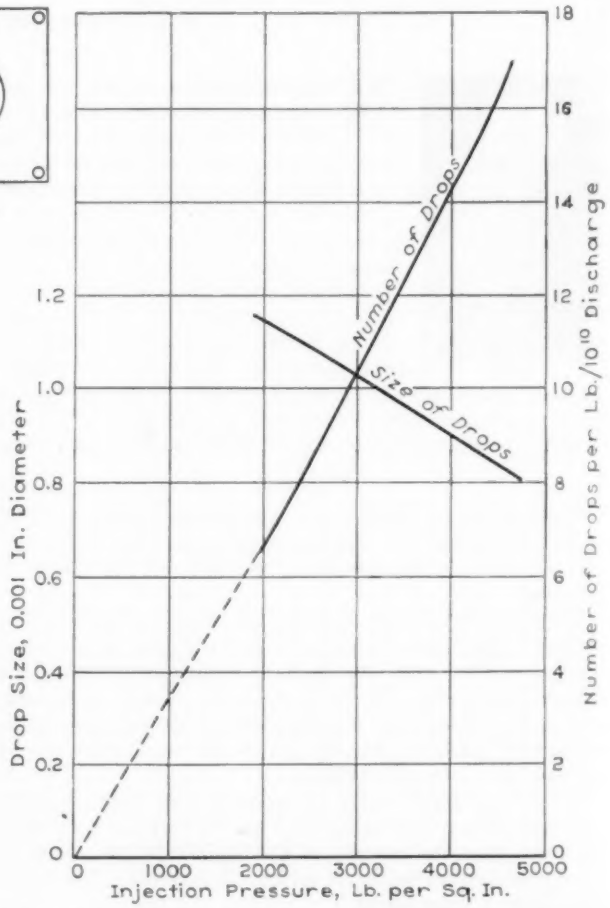


FIG. 5 RELATION BETWEEN DROP SIZE AND INJECTION PRESSURE
(Chamber, pressure, 145 lb. per sq. in.; orifice diameter, 0.024 in.)

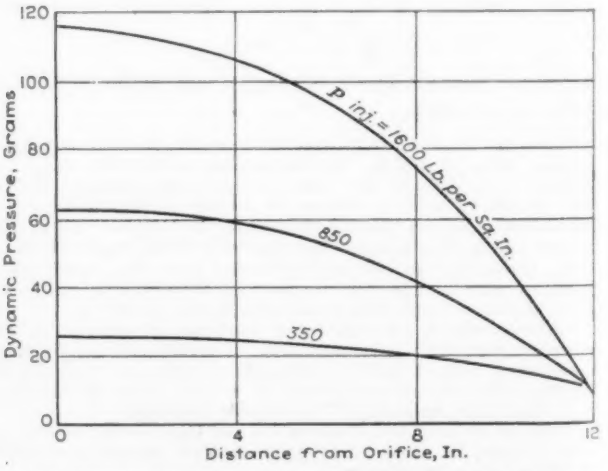


FIG. 6 RIEHM'S CURVES SHOWING RELATION BETWEEN DYNAMIC PRESSURE AND PENETRATION
(Orifice diameter, 0.305 mm.; orifice length, 1.0 mm.; chamber pressure, 300 lb. per sq. in.)

is the cam profile. If the peak pressure on the indicator card is too high, a more gradual rise is given to the cam profile. The cam profile has absorbed a disproportionate amount of attention from the designers and has diverted it from other important factors.

Through close measurements it was found that the cam profile is not responsible for many things attributed to it.

In Fig. 3 the upper curve shows how the needle of the cam-actuated spray valve would have moved had it followed the cam. The rate-of-discharge curve and the muzzle-velocity curve, both of which were determined experimentally, show that the valve opened about 17 deg. later and closed about 17 deg. earlier than it was supposed to, and the valve lift was also correspondingly smaller. This discrepancy was traced to the elastic compression and expansion of the valve stem. Fig. 4 shows schematically the spray-valve mechanism. The rocking arm, etc., was found to be sensibly rigid, and the outer end of the valve stem closely followed the cam. The trouble is that the valve end of the stem does not follow the other end. Under pressure the valve stem compresses like a spring, then it expands again. This change in length is far from being negligible. Initially the valve has to be pressed on the seat so that the high oil pressure shall not make it leak. This compression, for 6000-lb. injection pressure, amounted to about 0.004 in. Now when the cam begins to open, the valve stem expands, and until this initial stem compression is taken up no discharge will take place. Incidentally, this dead motion of the valve stem, during which the outer end of the valve stem moves outward and the inner end stands still, takes up more than half of the legitimate valve lift. This causes a delay in valve opening. The valve also closes earlier because the expanded valve stem reaches the seat sooner. The influence of the valve elasticity on the timing and metering varies with the injection pressure.

The elastic compression of the valve stem in the course of the injection was computed, and the dotted-line curve was obtained for 3000-lb. injection pressure as the theoretical valve lift. It sufficiently checks with the observations.

The beginning of the rate-of-discharge curve is significant. Instead of starting at zero, it starts at a high rate of discharge, indicating that the valve opened suddenly rather than gradually, the cam profile being a gradual curve. What caused the sudden opening? Before the valve opens, the oil pressure acts on a ring surface which is between the stem diameter and the seat diameter. When the valve opens, the oil gets behind the seat and exerts an additional pressure on the valve stem. This increase in pressure is practically instantaneous and causes a sudden push-back of the valve stem with a corresponding sudden discharge. This push-back is quite appreciable even with mechanically operated valves unless the valve stem is rather rigid. With the valve used, it figured as 0.0005 in. at 3000-lb. pressure, as shown in Fig. 3, and offers a partial explanation for the sudden initial rise in the rate-of-discharge curve. With spring-loaded valves this push-back of the stem should be more pronounced and suggests an explanation for a common annoyance in connection with solid-injection Diesel engines. Attempts to eliminate undesirable high maximum pressures by changing the fuel-cam profile did not meet with much success. Making the seat smaller and the valve more rigid is likely to produce the desired effect.

Injecting

For proper atomization, injection is not considered satisfactory unless the jet breaks up instantly upon leaving the spray nozzle. This requirement holds for the narrow cone sprays used in conjunction with precombustion chambers as well as with direct spraying. In order to have the spray already atomized when leaving the nozzle, a spray-tip velocity is needed of not less than about 120 ft. per sec. or an injection pressure of not less than about 1000 lb. per sq. in. for gas oil and accordingly more for heavier oils. If the injection pressure is insufficient, there is a solid core of a certain length, which is undesirable. If the injection pressure drops at the end of the injection, there is after-dripping.

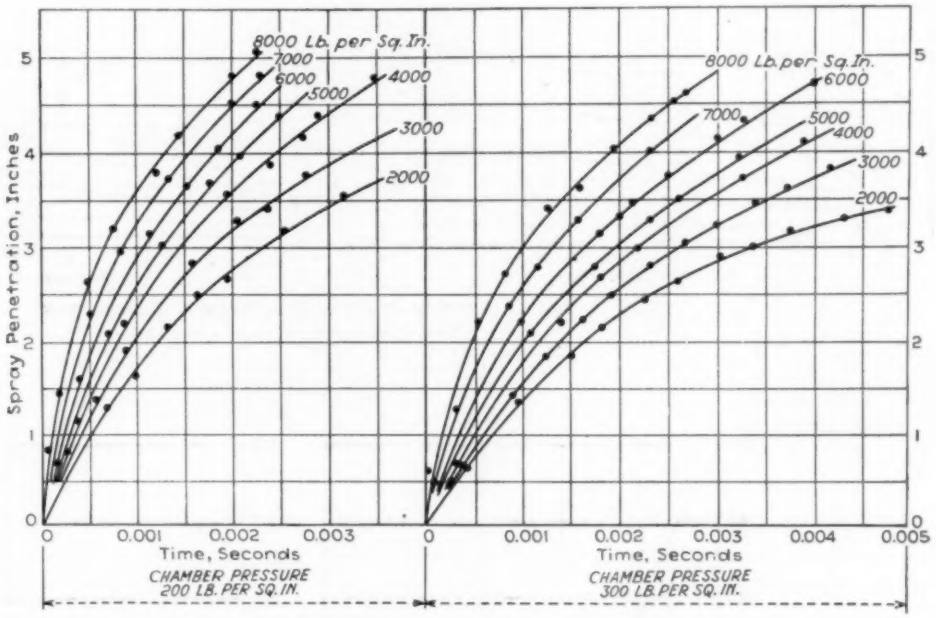


Fig. 7 N.A.C.A. Curves Showing Effect of Injection Pressure on Penetration

In direct-spray injection the jet should not only be broken up, but atomized into sufficiently small globules. According to Dr. Sass, to have good combustion in the A.E.G. engines, 20 per cent of the globules should be not larger than 0.0002 in., 30 per cent not larger than 0.0006 in., and preferably none larger than 0.002 in. Such an atomization can be obtained with an injection pressure of 4000 lb., a chamber pressure of 150 lb. (cold), and an orifice diameter of 0.024 in.

The globule sizes decrease with an increase in injection pressure. The number of globules per unit weight of fuel seems to be in direct proportion to the injection pressure, as shown in Fig. 5, most of the increase being in the small droplets. The average globule diameter for 3000 lb. is about 0.001 in., which is a good figure to remember. For other pressures it may be calculated from the relation mentioned. The drop sizes also decrease with smaller and shorter orifices or with centrifugal nozzles, but not very appreciably. For high-speed engines or engines with little or no turbulence a finer atomization is needed to accelerate combustion. The proper way to obtain it is by increasing the in-

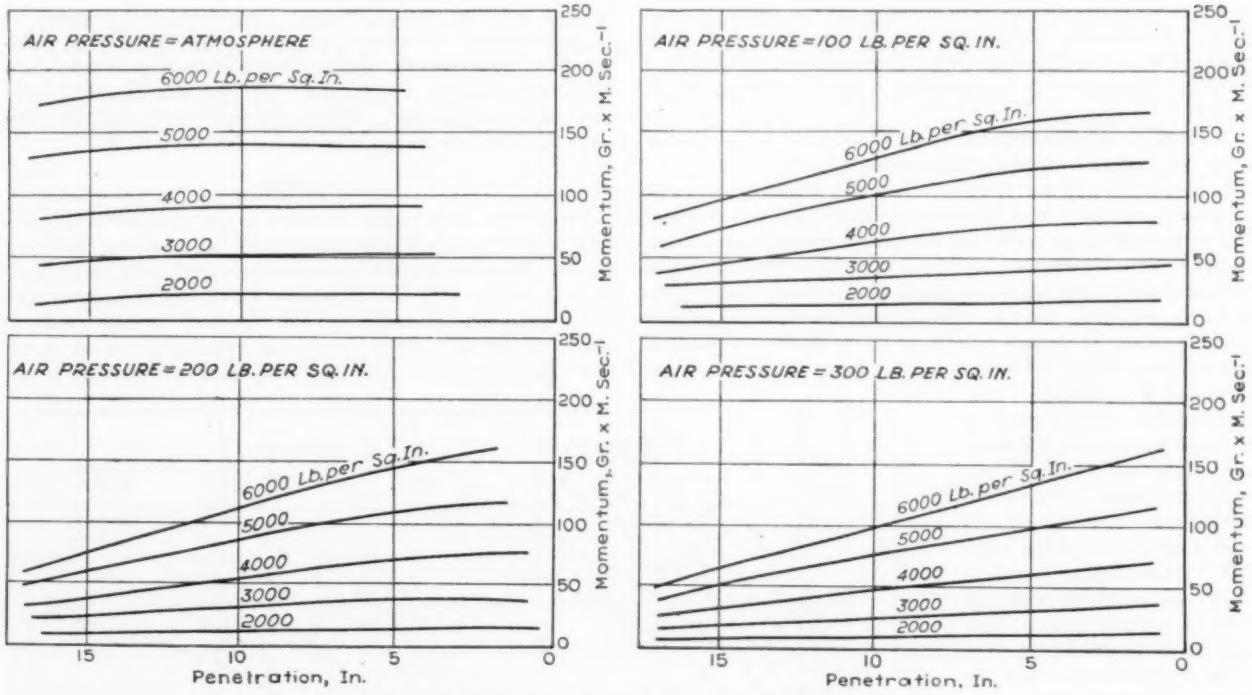


FIG. 8 RELATION OF SPRAY MOMENTUM TO PENETRATION
(Momentum = mass × mean velocity.)

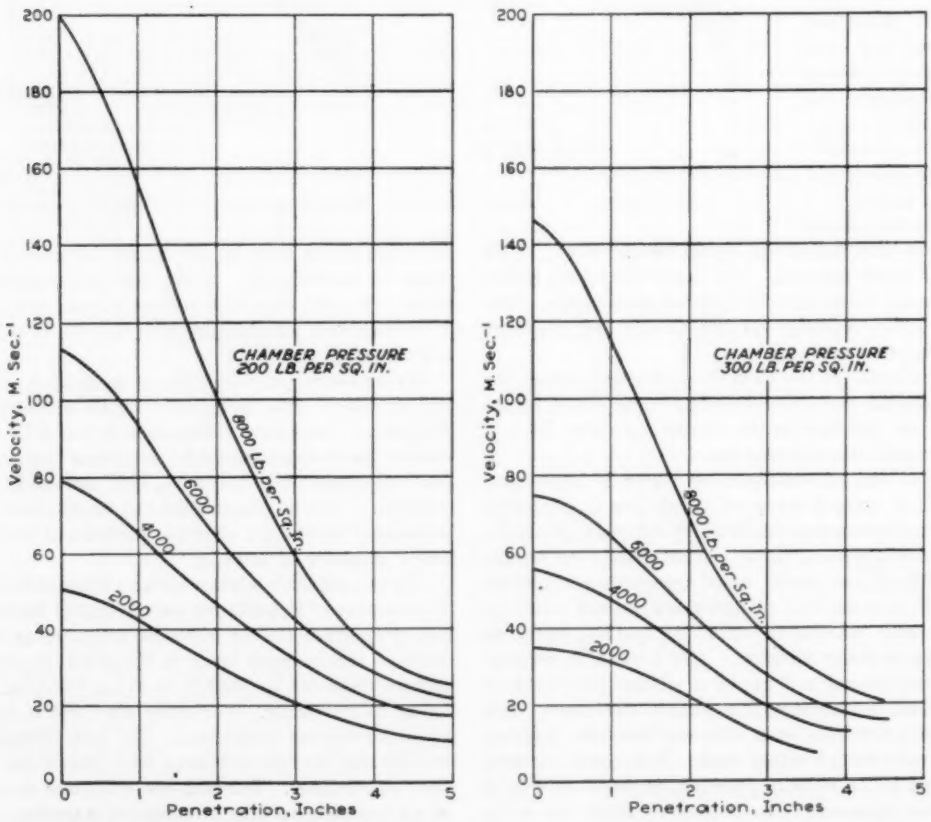


FIG. 9 N.A.C.A. CURVES REPLOTTED SHOWING DECREASE OF VELOCITY WITH PENETRATION

jection pressure. Heavier oils require higher injection pressures to produce the same atomization.

Spraying

If there is no turbulence, the oil spray has to fit the combustion chamber; if there is turbulence, it has to suit the turbulence.

An oil spray of 6000 lb. injection pressure in 200 lb. cold air (the density of which corresponds to 450 lb. hot air) will travel 28 in. With 1000 lb. injection pressure the penetration is about the same. In atmospheric air that spray shoots across the laboratory.

The fact that the spray penetration, precisely the total length of a horizontal spray, is independent of the injection pressure was discovered by Dr. Riehm six years ago (see Fig. 6). The Langley Field experiments, on the other hand, showed the penetration to increase with the injection pressure. That is at least the common interpretation given to the N.A.C.A. data, as shown in Fig. 7. Dr. Sass in his book pointed out the apparent discrepancy between Dr. Riehm's results and those of the N.A.C.A. and believed the former to be incorrect.

In the author's experiments intermittent injection was used instead of continuous injection, which was the strongest objection against Riehm's tests. The momentum of the spray (mass times velocity) was measured at various distances with the De Juhasz recording ballistic pendulum. A sample set of curves is shown in Fig. 8; the others are similar. It will be seen that the momentums drop off about in proportion to the distance, very rapidly at 300 lb. chamber pressure, but unnoticeably at atmospheric pressure. It will be seen that the momentum lines for various injection pressures intersect the horizontal axis practically in the same point. The distance of zero spray momentum, which is nothing else than the total penetration, is 23 in. at 300 lb. chamber pressure, 25 in. at 200 lb., 29 in. at 100 lb., and very long at atmospheric pressure, but the injection pressures does not seem to have much of an influence. The explanation is that the high-pressure spray is atomized into much finer droplets and the higher initial velocity is counteracted by higher air resistance.

These tests vindicated Dr. Riehm. Are, then, the N.A.C.A. tests incorrect? They are not, if interpreted correctly. The N.A.C.A. penetration curves are plotted against time. If by drawing tangents to the penetration curves, velocity is plotted against penetration, the curves shown in Fig. 9 are obtained. They appear quite convergent. It is conceivable that the curves for different injection pressures would have met on the abscissa axis if the Langley apparatus had been suitable to follow them so far. That checks with Dr. Riehm's and the author's results.

The difference in the curvature of the curves between Riehm's, Langley Field's, and the author's experiments can be explained easily. Riehm worked with a continuous spray, and the air set in motion kept the jet from losing much speed near the nozzle; therefore the curves are convex. At Langley they photographed the spray tip, the velocity of which is in the beginning slower, and later faster than the mean spray velocity. Therefore the curves start out convex and later become concave. The author measured what amounts to the mean velocity of an intermittent spray and obtained approximately straight lines.

High-pressure sprays and low-pressure sprays travel about the same distance in compressed air, but the high-pressure sprays travel faster. Therefore to obtain deeper penetration the increase of the injection pressure will not help much, but an increase in orifice dimensions will. However, in case of a high-speed engine the total penetration distance does not tell the whole story. The spray should penetrate and penetrate quickly. In order to make it penetrate more quickly and also to ignite more quickly an increase in injection pressure is quite in order.

Dispersion

To secure good combustion the space distribution of the spray is most important. In a non-turbulent type of combustion chamber the ideal is to distribute the oil in the combustion space so that it reaches every oxygen molecule. On the other hand, every part of the spray should be kept from hitting any surface which is below a certain temperature where it could coalesce or crack. In a turbulence type of combustion chamber the spray has to be directed so that it meets the air flow systematically.

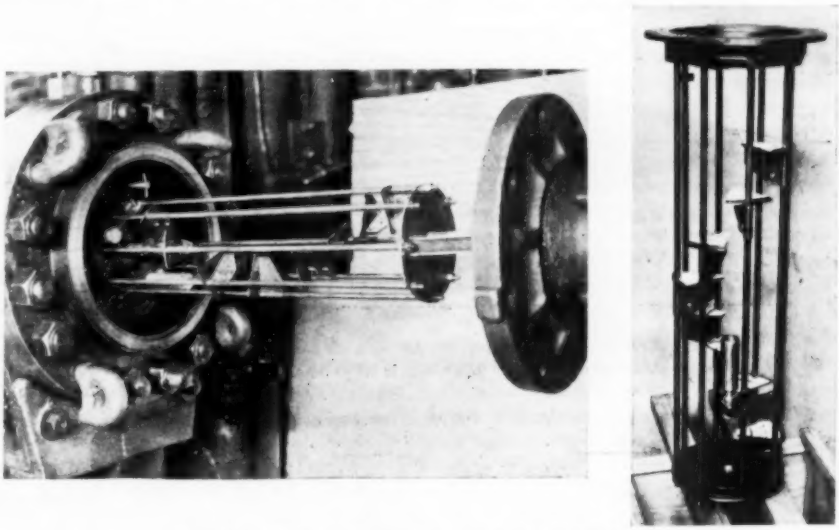


Fig. 10 "Spiral Stairway" for Dispersion Tests
(On the left, in place, before closing the pressure chamber; on the right, removed for weighing the segments.)

Little information was available on spray dispersion when the author started his experiments. At the suggestion of Professor De Juhasz, to determine the spray distribution various parts of the spray were caught in a cage holding segments of blotting paper located at various distances and angles like the steps of a spiral stairway. Weighing the blotting paper before and after injection, the difference indicates how much fuel passes the area represented by the blotting paper. Fig. 10 shows the "spiral stairway" with eight segments. The cage is placed in the pressure chamber, and one single shot gives the fuel distribution in the entire space.

Results obtained by the dispersion tests show that the spray is much wider and shorter in dense air than in the atmosphere, with simple cylindrical nozzles. In atmospheric air at a distance of 12 in. from the nozzle, 57 per cent of the total discharge is still within a 1-in. circle, while in 200-lb. air this percentage is only 8.7. Dispersion tests in the atmosphere have little value.

Fig. 11 gives a clear idea of the spray in compressed air. This refers to a Diesel oil spray at 4000 lb. injection pressure, 200 lb. chamber pressure, and atmospheric temperature, which is produced with a 0.025 by 0.050 in. orifice. A similar picture can be drawn for any spray nozzle and any operating condition. The author's spray is about 20 in. long and has a cone angle of about 25 deg. The heavy lines connect points having the same flux or angular density. If the oil particles would neither evapo-

rate nor be deflected by gravity, the flux lines would be straight and represent the path of flight of the particles. The envelope of the spray would then be a cone like Fig. 12, which shows the same spray in atmospheric air. With the actual spray in dense air this is approximately true near the nozzle, for about 8 in. distance with the author's spray. Then the gravity and evaporation make themselves felt more. The particles on the periphery evaporate or drop and the spray begins to "converge." It also becomes less and less dense and in slightly more than 20 inches it vanishes.

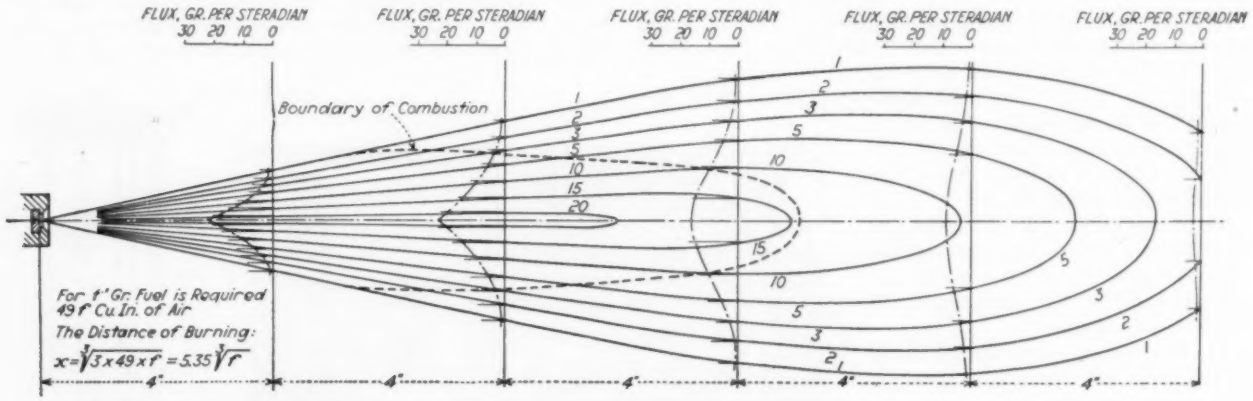


FIG. 11 SPACE DISTRIBUTION OF AN OIL SPRAY INJECTED INTO COMPRESSED AIR, EXPERIMENTALLY DETERMINED
(Orifice = 0.025 in. diameter by 0.050 in.; p oil = 4000 lb. per sq. in.; p air = 200 lb. per sq. in.; n = 202 r.p.m.; Diesel fuel oil.)

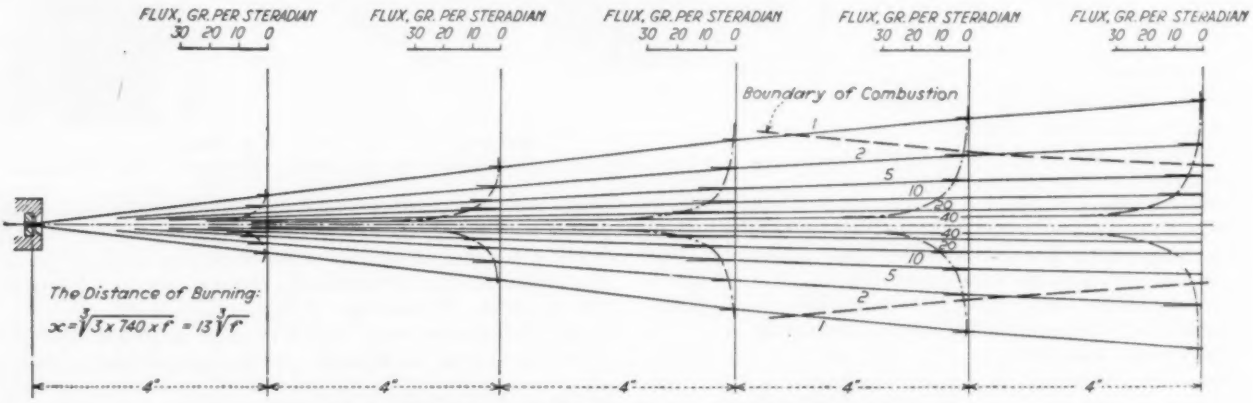


FIG. 12 SAME SPRAY AS SHOWN IN FIG. 11, IN ATMOSPHERIC AIR
(Orifice = 0.025 in. diameter by 0.050 in.; p oil = 4000 lb. per sq. in.; p air = atmosphere; n = 202 r.p.m.; Diesel fuel oil.)

The spray illustrated has a total weight of $^1/_{230}$ lb. and contains, according to Dr. Sass's measurements, 525 million droplets of from 0.0002 to 0.0015 in. diameter, which together have a total surface of 5.4 sq. ft.

It should not be inferred that the spray as shown represents the actual spray formed in the engine. The lighter portions will undoubtedly be torn apart by some turbulence. Some particles will burn before they get very far. In a low-speed engine a good portion of the fuel burns before the injection is over.

When traveling in hot air the oil particles burn. The dotted line marked "boundary of combustion" indicates the distances traversed before all of the oil burns. The adjacent oxygen is just sufficient to combine with the respective layer of oil, under the assumption that combustion begins at the nozzle with zero ignition lag and proceeds in a stagnant air free of turbulence. Therefore the rotational surface corresponding to the "boundary of combustion" is the "theoretical combustion chamber," the envelope of a theoretical combustion. But from a theoretical combustion chamber practical conclusions may be drawn. Spray interferences in a multi-spray engine should be avoided in or near the boundary of combustion if one does not want the drops to starve for the lack of oxygen. Farther away a spray interference is not so objectionable.

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Discussion

OLIVER F. ALLEN.[3] Professor Schweitzer is to be congratulated for calling attention to the prime importance of accuracy and uniformity in the manufacture of injection nozzles. The nozzle is of necessity a precision instrument, and its normal and regular functioning is inseparable from good Diesel-engine performance, especially with solid injection.

Equal care should be exercised in the selection of material

[3] New York, N. Y. Mem. A.S.M.E.

for the nozzle itself and for the valve seat, valve disk, and valve stem of the shutoff device.

The author mentions the elasticity of the moving parts. The matter of their weight is quite as important. Both affect the timing. In the mechanism shown diagrammatically by the author a very considerable cam travel is required for relieving the compression in the valve stem, disk, and seat when starting injection and again when closing the valve. The best results as to fuel economy seem to be obtained when the mechanism is such that the speeds of the parts while opening and closing the valve are as high as possible so as to reduce to a minimum the ill effects of the compression, expansion, and surging of both the moving and stationary masses. That is to say, injection should be started and stopped as quickly as possible.

In such engines as the Packard Aircraft Diesel the rate of acceleration of the pushrods, pump plunger, and valve parts is carried far beyond past performances. This is only possible with very light-weight parts of carefully selected materials, accurately and uniformly manufactured.

As the rotative speed of the engine, and consequently the number of cycles per minute, increases, the problem of metering becomes more difficult. With open nozzles and a considerable length of pipe line between the pump or controlling valve and the nozzle, as frequently occurs in slow-speed engines, the breathing of the pipe line, serious pressure surges, and perhaps other variables make the timing of both the beginning and the ending of injection somewhat uneven, especially with changing loads. The manufacturers try to shape and time the cams to compensate for such features. Fortunately at the slow speeds heretofore employed there is time for some irregularity in the injection control.

But what happens when the rotative speed is increased as required for automotive services such as rail cars, locomotives, buses and aircraft? The time available for the functioning of the fuel injection system becomes mighty short.

At, say, 200 r.p.m., a stationary engine, 10 deg. angular movement of the shaft, corresponding roughly to the injection period in a solid injection engine, represents about 0.009 sec. If an equal time is allowed for taking up lost motion, relieving compression in parts, etc., the total time for cam action is about 0.018 sec., if the release is instantaneous at the end of injection, but considerably more if the parts follow through according to the cam profile.

Assuming accuracy of timing of 3 deg. is required for good combustion control, the timing tolerance is of the order of 0.003 sec.

Considering the aircraft motor and assuming twice the angular movement for total cam action, up to the end of injection, and 5 deg. tolerance for good combustion control, at 2000 r.p.m. the time for cam action corresponding to 40 deg. angular movement is only about $^1/_8$ of that of the slow-speed engine. In other words, the total time for cam action of the aircraft motor corresponds to the tolerance of about 0.003 sec. for the accurate timing of the slow-speed machine. In the aircraft engine a 5-deg. tolerance represents about 0.0004 sec. This gives us a fair idea of the accuracy of manufacture, assembly, and adjustment required for the efficient results which have been accomplished with multicylinder injection-type high-speed heavy-oil engines.

To facilitate this result the tendency seems to be toward individual pumps for each cylinder, with the pump, valves, and nozzle all brought as close together as possible.

A. G. GELLALES.[4] The author is to be complimented for the presentation of this paper with such a wealth of information on the effect of nozzle design and test conditions on the spray produced. It represents a serious effort to clear some vexing problems on the subject. Further explanation, however, is in order if some points in the paper are to be fully interpreted.

One of the points is the application of the viscosity correction to the coefficient of discharge equation when a large orifice length to diameter ratio is used. The application of this correction is necessarily limited for a laminar type of flow through the throat of the orifice. This is possible only at the lower range of Reynolds' number with flows of small head difference and high kinematic viscosity. Information is lacking on the critical velocities and head losses for liquid flow through the diameter orifices used with high-speed compression-ignition engines; but if assumed that the critical velocities, through the orifices are similar to those in a parallel tube of the same diameter, and if the equation for critical velocities (Reference 1) established for tubes of $^1/_8$ in. and larger be employed, it will be found that for the Diesel oil, the throat velocities and other conditions identifying these injection-valve orifices, a laminar type of flow through the orifice is a rare occurrence. Take, for example, parallel tubes of 0.010 in. and 0.040 in. internal diameters, which represent about the smallest and largest orifice diameters used with high-speed oil engines. For other conditions, take an injection pressure of 5000 lb. per sq. in., Diesel oil having the properties of that used at the laboratories of the National Advisory Committee for Aeronautics, and oil temperature of 80 deg. fahr. Computations by the above method show the critical velocities to be 250 and 60 ft. per sec. for the smaller and larger tube diameters, respectively. The velocities through the throat of the orifice, unless of an excessive length, are always higher than these values, the ideal velocity with no orifice length being above 900 ft. per sec. From this it is seen, therefore, that before applying the correction suggested by the author of this paper, it should be ascertained whether or not the velocities through the orifice are below the critical region.

The National Advisory Committee for Aeronautics is extending the research on coefficients of discharge to include nozzles with maximum length to diameter ratios of 10. These nozzles will be tested for coefficient of discharge and spray penetration and dispersion. It is hoped that, at the conclusion of these tests, information will be obtained regarding the extent of head losses in the throat of the orifices of varying depths, and whether or not the equations for the larger sizes of tubes are also applicable to these conditions.

The fact that a length of orifice up to about four times the diameter has no effect on the coefficient of discharge, as given by the author, has been confirmed by tests concluded recently by the committee for a 0.014 in. diameter orifice for lengths between one and four times the diameter.

It is regrettable that Doctor Sass should have misinterpreted the results obtained by the National Advisory Committee for aeronautics spray photography apparatus on the ultimate penetration of the spray at different injection pressures. What the National Advisory Committee for Aeronautics spray photographs have shown was the development of the spray with time. The penetrations shown in the curves published in the various reports were those of the spray tip up to a maximum penetration of about 6 in. and at 0.004 sec. after the start of injection at the latest. That there is a difference in penetration with changes in injection pressure during this interval was clearly shown by these photographs. A set of curves of velocity against time, published in a report of the committee by Joachim and Beardsley (Reference 2), has shown the velocity of the spray tip to be the same at 0.002 sec. after the start of injection, regardless of the injection pressure.

[4] Assistant Mechanical Engineer, Langley Memorial Laboratory, Langley Field, Va. Jun. A.S.M.E.

ROBERTSON MATTHEWS.[5] Discussions of oil-engine nozzle design used to refer to the item of the compressibility of the fuel. Professor Schweitzer in his paper refers to the compressibility of nozzle valve stems. Owing to the increasing attempts to operate compression-ignition engines at higher and higher r.p.m., this attention to nozzle valve stems is commendable.

In Professor Schweitzer's paper considerable attention has been given to jet penetration and atomization. It is to be hoped that during the coming year those companies who are supporting this research will encourage by financial support research on directed turbulence in oil engines. The Hesselman engine, the Doxford, and the latest reported work of Ricardo, with his sleeve-valve engine, all have had as a primary item of consideration attention to provision for directed turbulence.

The fuel economy of all those engines is excellent. It is just possible that we have reached the useful peak of attention to fuel injection and penetration. It may be that in using the term oil engine we are concentrating too much on one substance. Though the term would be too indefinite for general use, it might open up new avenues of thought if once in a while, when we are in conference on oil-engine research, we apply to our baby the term "air engine."

As the nucleus of an item in research on turbulence, the writer should like to suggest consideration of the following presentation: Fig. 13 represents a conical jet projected into air, either

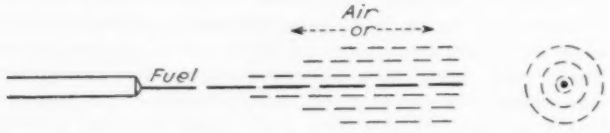


FIG. 13

stagnant or else moving somewhat parallel, either against or with the jet. Consider this jet as a cone made up of layers of fuel particles and fuel vapor.

Now let ignition occur. Combustion will begin not within the cone, where the mixture will be extremely rich, but will be at the boundary layers, and with an increase in pressure. Instead, however, of combustion causing dispersion of the cone of fuel through the surrounding air, the cone may be subjected to compression on all sides and, at least momentarily, suffer contraction. In such a case the benefit of the most desirable atomization could be considerably annulled.

Let Fig. 14 represent a body of whirling air passing a jet as in

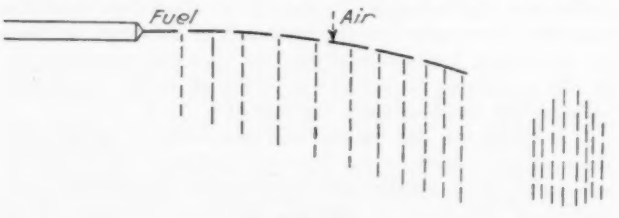


FIG. 14

the Ricardo sleeve-valve compression-ignition engine. As the jet becomes less dense, we may assume the air whirl bends it. But it does more. Instead of developing a cone of spray, the scrubbing action will develop elongated layers of spray and air which, when combustion occurs, will tend to spread out. If the Ricardo engine behaves as he states, that is, the air makes one complete whirl while the fuel-injection valve is open, the aforesaid layers should practically extend entirely around the combustion chamber.

[5] Detroit, Mich.

Turbulence probably explains why different experimenters have obtained good fuel economy with sprays of widely different fineness. That there is room for research on turbulence may be gathered from a comparison of statements concerning the Ricardo and the Doxford engines. Allowance must be made, of course, for the great difference in size and r.p.m. Ricardo speaks of fuel moving toward the center of the chamber because of a lower air pressure there. Regarding the Doxford engine, it is stated that there has been overheating of the cylinder walls due to fuel being thrown toward the walls.

Regarding what Professor Schweitzer says of the workmanship on orifices and proportioning orifices for different fuels, it may be well to consider whether for high-speed operation we are wise in attempting to use heavy fuels and residuals. Where would the automobile industry be today if it had been satisfied to attempt to use fuels that were simply left-overs on the market? This item may prove more significant if we remember that the day of spark ignition is not yet passed.

When with spark ignition and a concocted fuel an engine can be made to yield at 3300 r.p.m. a brake m.e.p. that no oil engine can touch, and—note this carefully—with a volumetric compression ratio of *ten*, there is room for thought.

Should development continue with spark plugs and such high compression, it will be interesting to see how soon the lay mind, with a cramped vocabulary, will be terming such engines near-Diesels.

It is doubtful wisdom for engineers to encourage the lay mind and salesmen to apply the term Diesel regardless of the cycle followed to every engine if it uses compression-ignition. What should we think if to every engine and turbine using vapor expansively some engineers insisted on applying the term Watt?

If the present loose use of the word Diesel continues to be applied to engines of all cycles, it will not be long before every test code, report, periodical, and patent specification, in order to make clear reading, will have to use a reference and footnote whenever the word Diesel is introduced.

The A.S.M.E. has already had much entertainment from such terms as boiler horsepower, efficiency ratio, and total heat. Why add to them? Our engineering diction, as in other professions, should grow with our achievements. It is not common knowledge as yet that compression-ignition for making fire a originated in Asia at some unknown date.

It is hoped such research as Professor Schweitzer represents will eventually give us a *combustion* indicator; something more in keeping with our research on oil engines than is the present engine indicator originated for work on steam engines.

AUTHOR'S CLOSURE

Mr. Gellales of the N.A.C.A. believes that the viscosity correction suggested by the author ought to be applied only in case of a laminar type of flow through the orifice, which is a rare occurrence. It is the opinion of the author that the suggested viscosity correction could be applied to advantage not only to laminar flow, but also to turbulent flow in the vicinity of the laminar region. No error would be caused even from using the formula far away from the laminar region, because the viscosity coefficient so calculated is very close to one for a large Reynolds number and small l/d ratios.

Neither can the author accept the view that a laminar flow in spray nozzles is a rare occurrence. It is rare with the N.A.C.A. because they are using a very thin oil. The viscosity of the N.A.C.A. Diesel oil (see Technical Notes No. 315) is less than the minimum of the A.S.M.E. tentative standard for light high-speed fuel oil. The A.S.M.E. tentative standard for heavy-duty Diesel engines is 10 times as viscous as the N.A.C.A. oil. On the basis of Mr. Gellales' figures with this oil, the critical

velocities are 2500 and 600 ft. per sec., which shows that with A.S.M.E. heavy-duty Diesel oil we actually are having laminar flow in the orifices. The Gulf black oil with which most of the Penn State tests were conducted is more than twice as viscous as the A.S.M.E. tentative standard, and still more viscous Diesel oils are in use. Laminar flow in Diesel orifices is rather normal than a "rare occurrence."

As intimated before, if one is in doubt whether a viscosity correction for the flow calculation would be in order, it is safe to apply the viscosity correction. It will do no harm, because the correction is insignificant in the turbulent region.

Mr. Allen's remarks emphasize the importance of the accuracy of the manufacture of Diesel injection parts and fully coincide with the views of the author.

Mr. Matthews recommends research on turbulence. Such an investigation is very desirable. The N.A.C.A. has done some work lately on this subject. The author would like to call the writer's attention to the fact that equally good results were obtained with turbulent and non-turbulent types of engines. While a familiarity with the characteristics of the oil spray is more important for the designer of an engine using limited or no turbulence than the other type, it is useful to both.

PET-52-1

Automatic Control of Oil-Pipe-Line Stations

First Report of the A.S.M.E. Special Research Committee on Automatic Pipe-Line Pumping Stations

By J. B. FORD,[1] J. B. McMAHON,[2] AND T. D. WILLIAMSON,[3] TULSA, OKLA.

This paper describes a fully automatic oil-pipe-line pumping station built by the A.S.M.E. Special Research Committee on Automatic Pipe-Line Pumping Stations. The station is in operation at the grounds of the International Petroleum Exposition at Tulsa, Okla., and is being used as an experimental laboratory to complete the development of automatic pumping and to fully test out and coordinate the equipment units used in its construction. When this development is completed, the committee will make a final report indicating all changes, and will give a description of the piping and electrical circuits finally resulting from this research.

THE transportation of crude oil as a step in its transformation into the refined gasoline and lubrication oil sold at filling stations is so remote from the consciousness of the layman that it is taken for granted, if indeed it is even given a thought. Oil pipe lining, however, has made great progress since the 1860's, when oil was transported in kegs on horseback and sold for medicinal purposes only under the now legendary name of "Seneca Oil," after the Seneca Indians of New York State who first used it, until today oil pipe lines extend into every section of the United States.



JAMES B. FORD



J. B. McMAHON



T. D. WILLIAMSON

These oil pipe lines reach out from the oil fields of the Mid-Continent and deliver their streams of crude to the Gulf Coast, the Great Lakes cities, and the centers of population on the Atlantic Seaboard. Similarly, the oil fields of California are connected with the West Coast cities by a system of pipe lines extending from southern California to Oregon.

Briefly, the oil is taken from the wells in fields by gathering pipe lines, which may be gravity-flow or pumping systems. From these gathering lines it is delivered into the trunk-line stations, where it is put into the lines under high pressure and sent on its way to the distant refineries.

Oil trunk lines are subject to all of the hazards of the seasons, and due to the dangerous nature and value of their burden, any failure on the line must be checked and repaired immediately. Changes in temperature result in tension and compression strains, and while the lines are protected against these by bends and expansion joints, a weak collar or weld occasionally will give way. Also there is the ever-present menace of river and creek crossings, which result in large breaks. Most oil lines cross the large rivers on the bottom, and shifting bars, quicksands, high water, caving banks, etc., all put strains on the crossing which might result in a break. The pumping-station operators have to be very vigilant and watch the flow charts carefully to detect any breaks and to take the proper steps to prevent excessive loss of oil.

This paper deals with some recent developments in the fully automatic pumping of oil by a system of electrically operated and remotely controlled pumping stations. While the automatic pumping of oil is an accomplishment much to be desired, the protection of the line and station in the event of a line break and the master control and remote supervision of the pipe-line pumping stations has to be developed along with it. In American pipe-line practice the average main trunk line is of 8-in. pipe size and operates at approximately 800 lb. per sq. in. working pressure. In recent years, however, a number of 10-in. and 12-in. lines have been built, and of course there are a number of short 6-in. lines working at pressures as high as 800 lb. per sq. in. The lengths of these trunk lines vary; some are 1600 miles in length, with pumping stations spaced about 40 miles apart along the line. Field gathering lines consist of pipe 2, 4, and 6 in. in diameter and work at more moderate pressures.

Individual pipe-line companies have used to some extent automatic pumping stations with emergency safety devices,

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[1] Tulsa Branch Manager, Chapman Valve Company. Mem. A.S.M.E. Mr. Ford was born in Georgetown, British Guiana, in 1896. He was graduated from the Massachusetts Institute of Technology in 1921 as Bachelor of Science in Naval Architecture. From 1922 to 1925 he was engaged in aeronautical engineering and research. He became associated with the Chapman Valve Manufacturing Company in 1925, first as mechanical engineer and later as branch manager. For the past four years had charge of their oil-field activities in the Mid-Continent area, with headquarters at Tulsa. He has been active in the standardization of oil-country equipment and the application of improved valve equipment to oil-field practice.

[2] Assistant Sales Manager, The Foxboro Company. Mr. McMahon was graduated from Carnegie Institute of Technology in 1921. He has had two years in selling pumping equipment and machinery to the oil industry and seven years in selling instruments to all phases of the oil industry. He assisted in the layout and design of the preliminary A.S.M.E. experimental station. He has been associated with the Research Committee on Automatic Pipe-Line Pumping Stations since its inception and now is Chairman of the Sub-committee on Instruments.

[3] President, The Petroleum Electric Company. Mr. Williamson was graduated from the University of Arkansas in 1909 and received Master's Degree in Electrical Engineering from the University of Arkansas in 1928. He has been actively engaged in selling electrical equipments and contracting electrical installations for the oil industry since 1917. He assisted in selecting equipments for the first automatic pipe-line station installed in the Mid-Continent field. He has been associated with the Research Committee on Automatic Pipe-Line Pumping Stations since its inception and now is Secretary of the committee. He designed the electrical system for the demonstration station.

Presented at the National Petroleum Meeting, Tulsa, Okla., October 6 to 8, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

such as high- or low-pressure shutdown, and there have been at least two attempts at fully automatic pumping; but these efforts have been hampered and were not complete due to a number of unavoidable handicaps extraneous to the problems of automatic pumping. The present developments under the auspices of the A.S.M.E. and through the cooperation of the International Petroleum Exposition at Tulsa have been brought to a successful completion by the unstinted contribution of experience and ideas by the engineers of the oil companies, the electric-power companies, and the pipe-line equipment companies. All of the work has been done cooperatively by committee action, and the station is set up and operating on the grounds of the International Petroleum Exposition at Tulsa for experimental development and further research. A less complete station was built and exhibited at the 1929 Oil Exposition, and the present very complete installation is being exhibited at the 1930 Exposition in October.

The trend to the use of electric motor drive for oil-pipe-line pumping stations has turned the thoughts of pipe-line engineers to the possible use of automatic control for the electrical stations. Improvements in deep-drilling methods and rapid oil production have resulted in raising large quantities of oil from high productive pools, with a consequent rapid decline of each new pool, and this competition in production has made it necessary to move large amounts of oil rapidly with hardly enough time to build new lines or even to loop the old lines.

The pipe-line companies, in order to keep pace with the rapid production of oil in the new pools, have been forced to add booster stations quickly to established lines in order to increase their capacity, although in many cases loops have been added paralleling old lines. Similarly, in the gathering lines in the field, the gathering stations have had to be large, and yet their usefulness at maximum capacity in any given field does not exceed three to five years. This condition has necessitated the use of equipment which is readily movable to new locations and of low first cost, even though the operating cost might be somewhat higher than more expensive equipment. Accordingly, the pipe-line companies have gone to the use of electrically driven centrifugal and reciprocating pumping units, to cope with the urgency of cheaply and quickly moving the excessive quantities of oil being produced in the flush oil fields. There is a trend also to the use of electrically driven units for main-line pumping stations. This use of electrical pumping has made possible the application of automatic operation and control to the pumping units, and there is every indication that the next few years will see numerous automatic installations.

In the cases where electricity is being used for pipe-line power, the pipe-line companies are looking hopefully to automatic operation for greater economy of power and labor. At an increased cost of approximately 40 per cent electric pumping stations can be made fully automatic and remotely controlled, and this applies equally as well to reciprocating pumping stations, electrically driven, as to centrifugal stations. At this time there is approximately 130,000 electric horsepower in use for oil pumping in the Mid-Continent and Southwest oil districts alone, and this development has practically all occurred since 1926. Nearly all gathering units which take the oil at the end of the gravity lines are now electrically driven, and although not automatic, there is every prospect that a number of them shortly will be made automatic. Also, a number of the main trunk lines carrying oil from the Mid-Continent north and to the seaboards through distances up to 1000 to 1200 miles are interspersed with electrically driven booster stations between the old oil-driven reciprocating pumping stations.

We will now enter into a general description of the Tulsa Automatic Pumping Station, its operation, and the means of accomplishing the things which it does. This unit has been designed for 7000 bbl. per 24 hours at 350 lb. working pressure, and by the operation of certain gate valves and switching from one electric circuit to another it will operate as one or the other of three types—first, as a main-line booster station, using centrifugal discharge pump; second, as a main-line pumping station, using suction pump on the field gathering lines and separate discharge pump into the main line; and, third, as a simple field gathering station, using reciprocating pump, putting the oil into the station tanks.

In the first case, as a main-line centrifugal booster station, the centrifugal pump draws the oil from the station tanks and discharges through the "line" to the tanks at the next station beyond. The reciprocating suction pump in this case is always idle until a break in the line occurs, when due to the increased discharge velocity through a flowmeter, the centrifugal main-line pump is shut down and closed off from the line by the electrically operated gate valves, while the reciprocating pump is started and thrown on to the line, drawing the oil back from the break and emptying it into the station tanks.

In the second case, the centrifugal pump is still used as the discharge pump through the "line," but is supplied by a reciprocating suction pump which draws the oil from the field gathering lines. In the event of a pipe-line break, the discharge pump is shut down automatically and the suction pump is transferred by means of the electric manifold valves to the broken line and withdraws the oil from the break, back into the station tanks.

In the third case, the centrifugal pump is not used. This case represents a simple electrically driven reciprocating pumping station such as is used for field gathering lines. The reciprocating pump picks up the oil and discharges it to the tanks at the main-line station, except in the event of a line break, when the pump is shut down by a low-pressure tripping gage. At the same time the electrically operated manifold valves are switched so that the pump will place suction on the discharge line to withdraw the oil from the break. The reciprocating pump is then automatically started again and runs until the line is emptied.

In all of the three foregoing cases the main-line pumps are started by high oil level in the station tanks. Twin tanks are provided, and the suction is switched automatically from the empty tank to the full tank as soon as one tank is pumped down to the pre-established low level. When both tanks are pumped down to the low level, it automatically shuts the station down and closes the proper valves to isolate the pumps from the oil-filled lines.

Regarding shutdown for line breaks, this is accomplished in the first and second cases (centrifugal discharge) by means of a flowmeter and velocity-actuated switches rather than by a low-pressure tripping device. The velocity-actuated shutdown is necessary for centrifugal pumping because it is possible in the case of a break at some distance from the station for the pressure to be maintained or even increased at the pump discharge. This would make a pressure-actuated shutdown inoperative. However, even though the pressure be maintained at the discharge of a centrifugal pump delivering into an open line, the velocity will always increase rapidly, depending of course upon the size of the break. Similarly, if the centrifugal pumps were operating against a closed gate or otherwise obstructed line, the pressure would be maintained, but the velocity would be reduced, and this would shut the station down.

In the third case, in which the reciprocating pump acts as a discharge, a high and low pressure operated trip is used, because in a reciprocating pump the discharge pressure drops immediately the head on the discharge line is removed, and, conversely, the pressure is increased for an obstructed line. In addition to protection against breaks and line stoppage, there are provided a

number of additional protective features such as shutdown for hot bearings, shutdown for excessively high temperature in station (fire hazard), and other details to be described later. All of these protective features are interconnected with the master control system, which indicates instantly on the central control panel the nature of the stoppage and the cycle of the operation occurring at the station during and after the shutdown.

Mention should here be made of the master control system, although this will be described in considerable detail later. The isolated location of pumping stations and the fact that they operate night and day and independently of weather conditions make it necessary that a system of remote supervision and control be provided. The stations are designed to operate entirely without manual attention, and if a station be automatically shut down and taken off the "line," due to line break, hot bearing, fire, or other trouble, it is necessary that this be known immediately and the cause of shutdown indicated to the line supervisor so that proper steps can be taken to place it back on the line.

The master control system that was developed for the Tulsa Automatic Station will permit of transmitting 80 or more operations and indications simultaneously in either direction over a two-wire copper or iron telephone circuit, or it can be handled equally well over a phantom circuit. It has not been found necessary to use more than ten or a dozen indications in the Tulsa station, but in a fully automatic main trunk line with twenty or more multiple-unit pumping stations, this master control system would doubtless be used to capacity.

The types of pipe-line pumping stations, which have just been briefly described, were selected by the pipe-line representatives, members of this research committee, as practical examples for the applications of automatic controls. The operating conditions and the emergencies which required protection were also outlined by these members. Thus, the automatic pumping station which has been built at the exposition grounds represents the practical operating conditions which will actually be found in gathering and pipe-line stations.

With this paper are flow charts and outlines of the sequence of operations for the types of stations previously described. Reference to these will give a clear understanding of the arrangements of the equipments and the function which each has been selected to perform.

A previous paragraph refers to the several types of protective devices which have been selected, corresponding with characteristics of the equipment with which they are to be used. These selections were made after a considerable amount of investigation, in which all available facts were secured from pipe-line operating superintendents as well as from engineers representing the equipment companies.

Other features of protection for station equipment which are not peculiar to this problem were found necessary. One of these is the starting of centrifugal pumps against closed gate valves, since a serious overload is thrown on the pump motor when the pump is started against an open line. Provision is made that the centrifugal pump will never start except against a closed gate, which is opened in steps by electrical relays through a definite time interval, after full operating pressure has been built up against the gate.

It should be emphasized at this point that it has not been found necessary to build any special equipment for this station. Every piece of equipment selected has been used successfully on other applications. For instance, the motor-operated valves are of a standard make with positive-limit switches on both opening and closing, so that jamming of the valve or the seat to shut down the valve motor is unnecessary; at the same time, if jamming occurs due to foreign material becoming lodged in the valve body, an overload relay protects the valve motor. These valves are illustrated in Fig. 9.

The liquid-level gages used are of standard makes, with ordinary high and low electric contacts. These are illustrated in Fig. 6 at *K* and *LL*. Diaphragm boxes are used. A test was made using a small flow of air continually being bled through the liquid, and the pressure on the air line, which is equal to the liquid head, being transmitted to the gages, which was found unsatisfactory, due to pulsation of instrument needles.

In the following part of the paper reference is made to the flow charts (Figs. 1, 2, and 3) and the diagram of the layout (Fig. 4), the photographic illustrations (Figs. 5 to 11) and Tables 1, 2, and 3, describing the operations in Cases 1, 2, and 3.

The station referred to as Case 1, and shown in Fig. 1 and Table 1, functions as a main-line booster, receiving fluid by gravity or pressure into the station tanks *T*-1 and *T*-2, either from field lines or another booster station. Two tanks are provided enabling the fluid to be received into one while being pumped out of the other. This automatic control is operated by means of liquid-level instruments *LL*-1 and *LL*-2; when a tank is filled to the level setting of the instrument, the motor-driven valves *A*-1, *A*-2, *A*-3, and *A*-4 are operated to so change the pipe connection that the fluid is pumped from the filled tank and flows into the one which is partially emptied. Should either tank be pumped to a predetermined minimum level, as indicated by the liquid-level instruments representing lack of fluid coming into the station, the centrifugal pump is stopped. When the fluid reaches the high-level setting in either tank, the pump is automatically started, and the station continues to function under normal conditions. A centrifugal pump is used to discharge fluid from the station, and protection against broken pipe lines is provided by means of a flowmeter *FM*-1, as previously described. When a break occurs, the centrifugal pump is stopped, motor-driven valves are operated to change the pipe connections, and a reciprocating pump, controlled by a definite time relay, is started, to draw fluid from the broken line and return it to one of the station tanks. At the end of the time for which this relay is set, the reciprocating pump is stopped, motor-operated valves are closed, and an alarm is sounded. The flowmeter *FM*-1 serves also to measure the volume of fluid delivered into the pipe line by this station and to check with the volume received at the next station. Flowmeter *FM*-2 is used to show the delivery to the next station, and operates an electric alarm when a predetermined decreased flow occurs, which would indicate line-break conditions between these two stations. The meter also makes it possible to measure the amount of liquid lost in the break.

Tank *T*-3 represents the receiving tank at the next station. The pumping station represented by Case 2, and shown in Fig. 2 and Table 2, is identical in every way with the station of Case 1, with the exception that tank *T*-3 represents a field storage tank, and the reciprocating pump is used to deliver fluid from this tank to the station tanks *T*-1 and *T*-2. This operation is controlled by means of an electrically wound time switch, equipped with mercury-tube electrical contacts. The period of time during which this reciprocating pump is to operate is set in this time switch. Motor-driven valves are operated to make proper piping connections, and the reciprocating-pump motor is electrically interlocked with the valve *A*-6 on the discharge side of this pump to start the motor when the valve is fully open.

In this case tank *T*-3 serves the double purpose of field tank, from which fluid is being withdrawn by the reciprocating pump, as well as receiving tank at the next station, into which the centrifugal pump discharges.

In case of a pipe-line break, the duty of the reciprocating pump

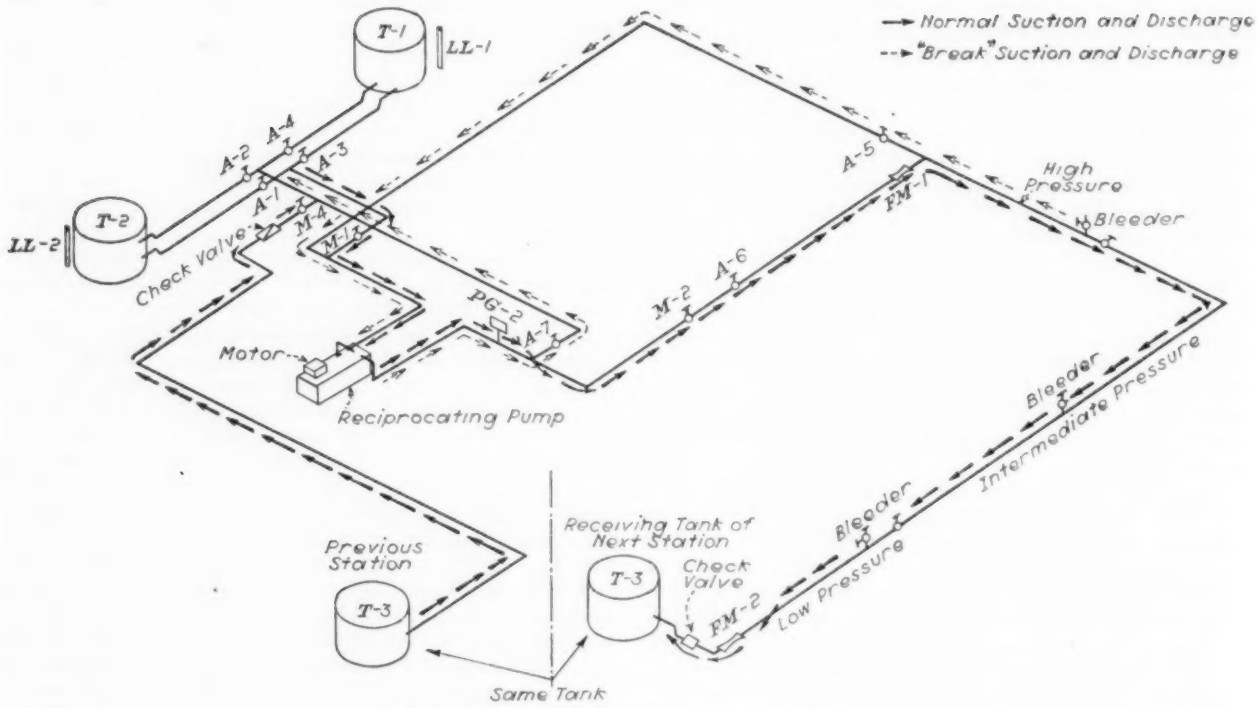


FIG. 1 FLOW SHEET COVERING OPERATION OF CASE 1

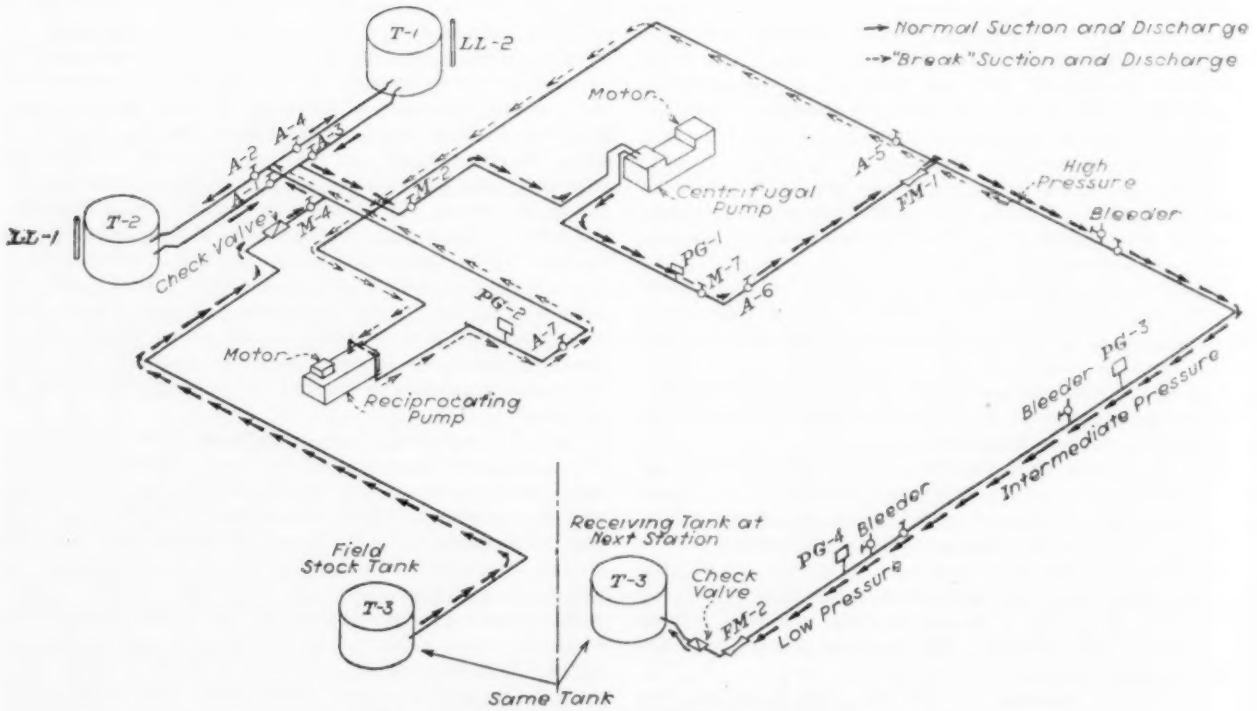


FIG. 2 FLOW SHEET COVERING OPERATION OF CASE 2

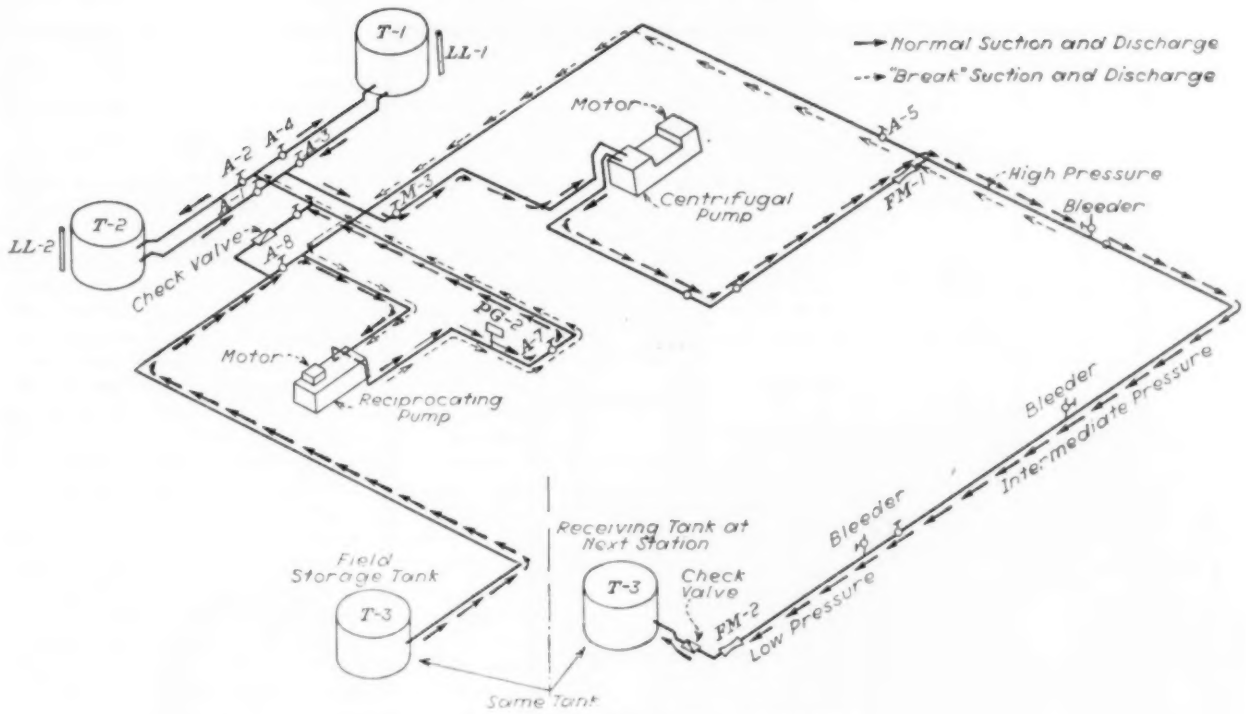


FIG. 3 FLOW SHEET COVERING OPERATION OF CASE 3

TABLE 1 OPERATION OF CASE 1

Centrifugal pump as discharge pump delivering through the "line" to tank *T*-3. Suction pump idle except in event of break.

A-1, *A*-2, *A*-3, and *A*-4 automatically "switch" the tanks, and all operate at the same time and are controlled by the high level in either tank. *A*-2 and *A*-3 close as *A*-1 and *A*-4 open, when *T*-2 fills up; and vice versa when *T*-1 is full.

Position of manual valves to produce this Case 1: *M*-1 closed, *M*-2 closed, *M*-3 open, *M*-4 closed, *M*-7 open.

Automatic valves before cycle starts: *A*-5 closed, *A*-6 closed, *A*-7 closed, *A*-8 closed.

Starting Cycle:

Cause: High level in either tank *T*-1 or *T*-2, caused by opening *M*-4.

Starts centrifugal pump, and when normal operating pressure is reached, as indicated by *PG*-1, *A*-6 starts to open intermittently through a definite time relay, and when *A*-6 is fully open, the electrical circuit on *FM*-1 is energized, which then causes *FM*-1 to function for abnormally high flows.

Normal Operation:

A-6 is fully open, *A*-5, *A*-7, and *A*-8 remain closed.

Normal Shutdown:

Cause: Shutting *M*-4, which causes low level in either *T*-1 or *T*-2.

Centrifugal pump stops. *A*-6 closes.

When a Break Occurs:

From the abnormally high flow through the flowmeter *FM*-1, a relay is operated, which starts *A*-6 closing, stops centrifugal pump, opens *A*-5, opens *A*-7, and (when *A*-7 is fully open) actuates a definite time relay which starts the suction pump and runs it for a definite set time.

At the end of this period, *A*-7 starts to close, stopping the suction pump, and *A*-5 closes.

NOTE: *FM*-1 will be used in this case for not only measuring volume, but also for control work when abnormally high volumetric delivery occurs. *FM*-2 will be used in this case on the receiving end for measuring volumes as well as giving an alarm when a predetermined decreased flow occurs, and measuring amount of liquid lost in break.

TABLE 2 OPERATION OF CASE 2

Centrifugal pump as discharge pump discharging through the "line" to tank *T*-3. Suction operating from tank *T*-3 and instead, in the event of a break, on the discharge end of the line only.

A-1, *A*-2, *A*-3, and *A*-4 automatically "switch" the tanks, and all operate at the same time and are controlled by the high level in either tank. *A*-2 and *A*-3 close as *A*-1 and *A*-4 open, when *T*-2 fills up; and vice versa when *T*-1 is full.

Position of manual valves to produce this Case 2: *M*-1 closed, *M*-2 closed, *M*-3 open, *M*-4 closed, *M*-7 open.

Automatic valves before cycle starts: *A*-5 closed, *A*-6 closed, *A*-7 closed, *A*-8 closed.

Suction Cycle:

Starting: Cause—Time clock or relay or manual switch. *A*-7 and *A*-8 open. When *A*-7 is fully open, suction pump starts.

Stopping: Cause—Time clock or relay or manual switch. *A*-7 starts to close, suction pump stops, and *A*-8 closes.

Starting Discharge Cycle:

Cause—High level in either *T*-1 or *T*-2 or manual switch. Starts centrifugal pump, and when normal operating pressure is reached, as indicated by *PG*-1, *A*-6 starts to open intermittently through a definite time relay, and when *A*-6 is fully open, the electrical circuit on *FM*-1 is energized, which then causes *V*-1 to function for abnormally high flows.

Normal Discharge Operation:

A-6 fully open, *A*-5 closed; *A*-7 and *A*-8 are both open if the suction pump is running; *A*-7 and *A*-8 are both closed if the suction pump is shut down.

Normal Discharge Shutdown:

Cause: Low level in either *T*-1 or *T*-2 or manual switch.

Centrifugal pump stops and *A*-6 closes.

When a Break Occurs:

From the abnormally high flow through the flowmeter *FM*-1, a relay is operated which starts *A*-6 closing, stops centrifugal pump, opens *A*-5, opens *A*-7 (if not open), closes *A*-8, and (when *A*-7 is fully open) automatically transfers the control of the reciprocating pump from the time clock to a definite time relay which starts the reciprocating (suction) pump (if it is not running) and runs it for a definite set time.

At the end of this period (the time set on the relay), *A*-7 closes, the suction pump stops, and *A*-5 closes.

NOTE: *FM*-1 will be used in this case for not only measuring volume, but also for control work when abnormally high volumetric delivery occurs. *FM*-2 will be used in this case on the receiving end for measuring volumes as well as giving an alarm when a predetermined decreased flow occurs, and measuring amount of liquid lost in break.

TABLE 3 OPERATION OF CASE 3

Centrifugal pump eliminated. Reciprocating pump as discharge pump delivering through the line to tank *T*-3, except in the event of a break, when it puts suction on discharge end of line.

A-1, *A*-2, *A*-3, and *A*-4 automatically "switch" the tanks, and all operate at the same time, and are controlled by the high level in either tank. *A*-2 and *A*-3 close as *A*-1 and *A*-4 open, when *T*-2 fills up; and vice versa when *T*-1 is full. When break occurs, however, *A*-1 and *A*-3 both close, while *A*-2 and *A*-4 continue to alternately open and close.

Positions of manual valves to produce this Case 3: *M*-1 open, *M*-2 open, *M*-3 closed, *M*-4 closed, *M*-7 closed.

Automatic valves before cycle starts: *A*-5 closed, *A*-6 closed, *A*-7 closed *A*-8 closed.

The control circuit for Case 3 is now transferred to a separate system of wiring than in Cases 1 and 2, by a double-throw switch.

Starting Cycle:

Cause: High level in either *T*-1 or *T*-2 or caused by opening *M*-4.

A-6 starts to open, and when *A*-6 is fully open, reciprocating pump starts.

Normal Operation:

A-6 is fully open; *A*-5, *A*-7, and *A*-8 remain closed. The reciprocating pump runs continuously.

Normal Shutdown:

Cause: Low level in either T-1 or T-2 due to closing M-4 or manual switch.

A-6 starts to close, and reciprocating pump stops.

When a Break Occurs:

From the abnormally low pressure at the gage *PG*-2, a relay is operated which starts *A*-6 closing, shutting down pump, opens *A*-5, opens *A*-7, closes *A*-1 or *A*-3, whichever of these two valves happens to be open so that the pump is prevented from continuing to take suction from the tanks *T*-1 and *T*-2, and (when *A*-7 is fully open) automatically transfers the control of the reciprocating pump from normal operation and shutdown to a definite time relay which starts the pump and runs it for a definite set time.

At the end of this period, *A*-7 starts to close, stopping the suction pump, and *A*-5 closes.

NOTE: *FM*-1 will be used only to record the volume in this case. *FM*-2 will be used on the receiving end for giving an alarm when a predetermined decreased flow occurs.

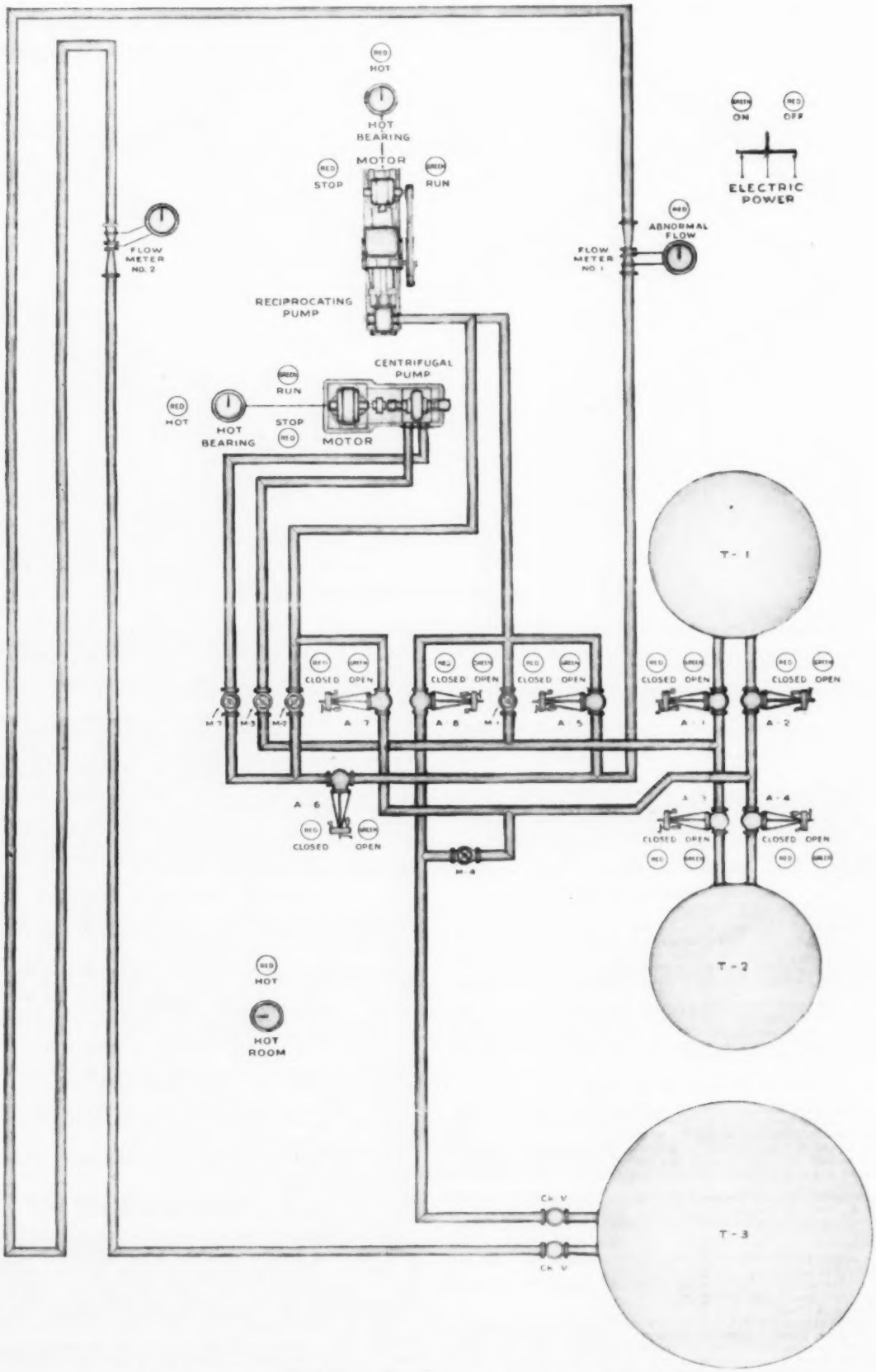


FIG. 4 DIAGRAMMATIC LAYOUT OF AUTOMATIC PIPE-LINE PUMPING STATION

is transferred from that of a field-line pump to a suction pump, to draw fluid from the broken line and deliver it into the station tanks *T*-1 and *T*-2. Necessary changes in the piping connections are automatically made by motor-operated valves.

The pumping conditions represented by Case 3, and shown in Fig. 3 and Table 3, are those of a simple reciprocating-pump station, such as is used for field gathering lines and small booster stations. The centrifugal pump is not used. The reciprocating pump delivers fluid from the station tanks *T*-1 and *T*-2 through the pipe line to tank *T*-3 of the next station. In case of a line break, motor-driven valves are operated to change the piping connections, and the operation of the reciprocating pump is reversed, drawing the fluid from the pipe line and returning it to the station tanks.

In the operation of this station the flowmeter *FM*-1 is used only to record the volume of fluid being pumped and flowmeter *FM*-2 to record the volume being received at the next station. The difference between these two records represents the fluid lost due to a break in the pipe line. Flowmeter *FM*-2 is so equipped as to give an alarm when a predetermined decreased flow, which would indicate a line break, occurs.

The operation of the liquid-level instruments *LL*-1 and *LL*-2 is identical with that described in Cases 1 and 2.

The mechanical equipments and devices described in the preceding paragraphs, such as flowmeters, motor-operated valves, liquid-level instruments, etc., serve as the direct means of accomplishing the automatic operations in this pump station. In order to properly correlate these operations, to tie them together in their proper sequence, and to provide such features as



Fig. 5 Outside View of Automatic Pumping Station

time delay and remote control in their operations, we have employed electrical energy. In this section we will describe the various electrical equipments used, their functions, and the sequence of operations.

The previous section has described in detail the three types of pump stations for which automatic equipments have been applied. Supplementing this description of the mechanical equipments and their operations, the electrical devices used in conjunction with them will be described for each type of station, in the order previously given.

Case 1. The electrical equipments and devices used in this type of station are illustrated in Fig. 6, and may be briefly described as follows:

(*a*) The mercury-type time-delay relays operate on the basis of a solenoid, when energized, pulling up plungers. The time delay is accomplished by means of a cup filled with mercury, having a small hole in the bottom through which the mercury escapes, the maximum time delay obtainable being three minutes.

(*b*) The motor-type time-delay relay, driving through a train of gears, operates contacts the maximum delay of which is 30 min.

(*c*) The electrically rewound time switch, with mercury-tube contacts, serves to energize and de-energize electrically, certain equipments at predetermined times.

(*d*) A mercoid-type pressure switch closes an electrical contact when the pressure setting of the device has been attained.

(*e*) The control stations for the motors of the automatic valves consist of push buttons to "open," "close," and "stop" the valves, with lamps to indicate when electric power is available and also the position of the valves, whether fully opened or fully closed.

(*f*) As shown in Fig. 7, a large number of relays serve to transfer the electrical energy between equipments and to so interlock them as to insure the proper sequence of operations. These relays consist of both the "single pole" and "double pole"

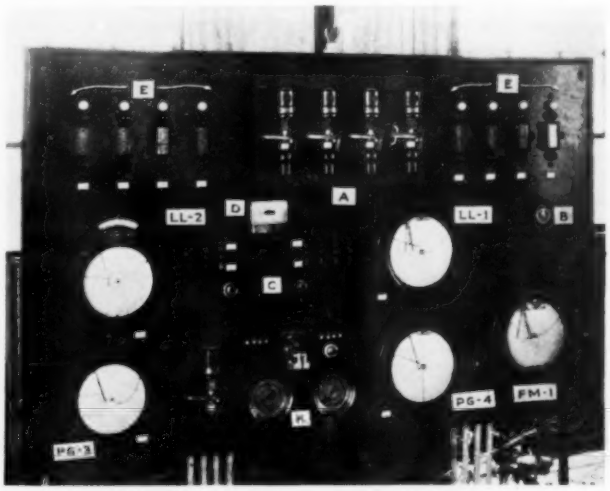


Fig. 6 Front View of Control Panel

types, as well as "single throw" and "double throw," as required to perform their function.

(*g*) The control equipment (Fig. 8) for the 25-hp., 440-volt motor driving the reciprocating pump consists of magnetic-operated contacts installed under oil, to insure safety when used in a gaseous room. Overload protection is provided in thermal-type overload relays which, when operated, actuate a mercury tube, opening the holding-coil circuit for the main contacts and allowing them to open. The motor is controlled at any number of points by opening or closing this holding-coil circuit.

(*h*) The control equipment for the 60-hp., 440-volt motor driving the centrifugal pump is identical with that used in the control of the 25-hp. motor, except for the larger capacity.

(*i*) The motor used for driving the reciprocating pump is standard squirrel-cage type, rated 25 hp., 440 volt, three phase, 60 cycle, 1200 revolutions.

These circuits connect with the electrical contacts which are provided in the various meters and instruments previously described and which become a part of the electrical system.

Operation of Station

The starting of the discharge pump is accomplished when the liquid level in either of the station tanks *T*-1 or *T*-2 reaches a predetermined setting, as indicated by the liquid-level instruments. The closing of the electrical contacts in these instruments, through a system of interconnecting relays, energizes the holding coil of the motor control, and the 60-hp. motor and centrifugal pump are started. This pump operates as long as there is fluid in either station tank *T*-1 or *T*-2, and is stopped when the fluid in either tank reaches a predetermined minimum

level as indicated by the liquid-level instruments. In this case the electrical contacts in these instruments, closing the circuit through relays, de-energize the holding coil of the motor control, and the motor and pump are stopped.

As outlined in the previous section in connection with the operation of the station, certain motor-operated valves are opened or closed to accomplish the desired results. These operations are performed electrically, by interconnecting through relays the allied equipments with the "open" or "close" buttons of the valve-control stations. The results obtained are similar to an operator having closed the corresponding button of the motor-control station.

An explanation has been given of the several reasons for starting a centrifugal pump against a closed valve, which should be opened

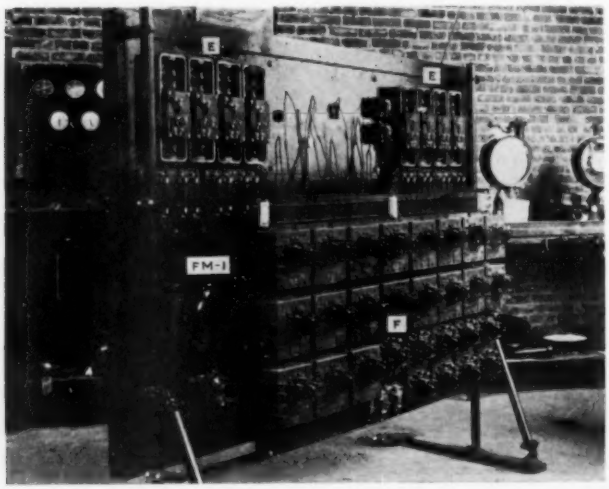


FIG. 7 BACK VIEW OF CONTROL PANEL

gradually, allowing the pressure to build up on the discharge side of the valve, equal to that between the pump and the valve. This result is accomplished automatically by means of a mercury pressure switch (item *d*) and three mercury-type time relays (item *a*). The mercury pressure switch is connected in the main pipe line between the pump and motor-operated valve. Referring to Fig. 6, when the circuit is closed, energizing the coil of relay 1, this closes within one second, energizing the opening contact of the valve control. At the same time the coil of relay 2 is energized and within ten seconds closes contacts which causes the valve to "stop." At the same time the coil of relay 3 is energized, and within twenty seconds the "open" contacts of the valve control are energized, and the valve starts to open. At the same time the coils of both relays 2 and 3 are de-energized and automatically reset. The coil of relay 2 is again energized, and within ten seconds causes the valve to "stop." Thus this sequence of operations, opening for ten seconds, stopping for twenty seconds, is continued until the valve is fully open, when the limit switch in the valve mechanism causes the coils of all three relays to become de-energized, and they are reset, ready for another opening operation.

Should a break occur in the line beyond this station, the sequence of operations would be performed as previously described in detail. The electrical functions in this connection are outlined as follows: Excess flow of fluid through the flowmeter *FM*-1 closes an electrical contact, which, connecting through relays, energizes a motor-driven-type time relay. This relay is set to operate for a maximum time which would be required to empty the pipe line. The motor-operated valve on the discharge side of the centrifugal pump is closed by automatically operating the valve-control station, and those on the suction and discharge sides of the reciprocating pump are opened by similar means. When the motor-operated valve on the discharge side of the reciprocating pump is fully open, a relay is closed by the limit-switch mechanism in the valve, thus allowing the contactor in the motor-control equipment to close, starting the reciprocating pump to operate. This pump will then operate to draw the fluid from the pipe line, discharging into the station tanks, for the period of time set in the motor-operated time relay. At the end of this time the motor is stopped, and all of the motor-driven valves on the discharge side of the station are closed. At the time a break occurs, followed by the foregoing sequence of events, an alarm relay is also closed, to notify the superintendent or pumpers, at distant points, of the trouble. Also a relay is actuated which prevents the station from again starting automatically until the break has been repaired and the relay reset by hand.

Case 2. The operating conditions of this station are similar in every way to those of Case 1, with the exception that the reciprocating-pump unit is called upon to serve a double purpose. In addition to evacuating the pipe line in case of a break, the operation of which has been described under Case 1, in this case the reciprocating pump is to be used to "boost" fluid into the pump-station tanks from field or flow tanks. The latter operation is to be performed during certain fixed hours of the day or night. For this control an electrically rewound time switch (item *c*) is utilized. When this pump is to be used for

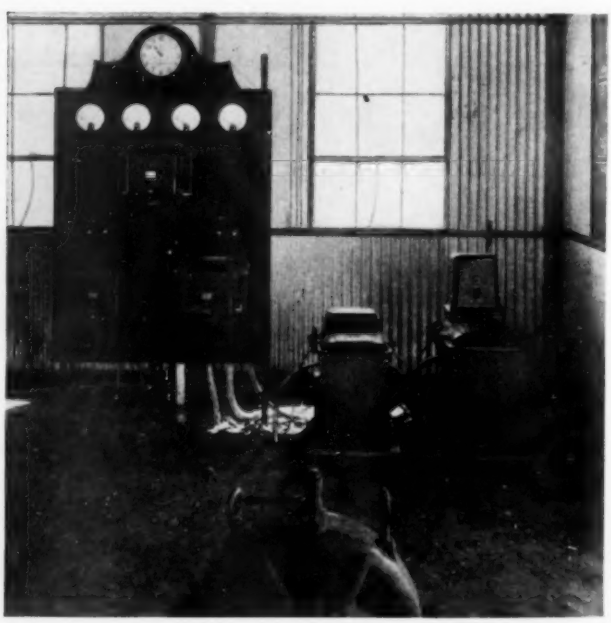


FIG. 8 MOTOR-CONTROL PANEL AND MOTOR-STARTING EQUIPMENT

bringing fluid from the field tanks, the electrical contact in the time switch having closed, motor-operated valves on the suction and discharge sides of the pump are automatically opened. When the valve on the discharge side of the pump is fully opened, a relay operated by the limit switch of the valve mechanism causes the contacts in the motor control to close, and the motor and reciprocating pump are started. At the end of the time set in the time switch, the valves on the suction and discharge sides of the reciprocating pump are automatically closed. When the valve on the discharge side of the pump starts to close, a relay actuated by the valve-limit switch causes the contacts of the

motor control to open, and the motor and reciprocating pump are stopped.

In case of a break in the pipe line, control of the reciprocating pump and motor is transferred from the time switch to the motor-operated time relay, and at the end of the service of emptying the pipe line, the entire station is shut down until the trouble is cleared and a relay reset by hand. All other operations and automatic controls are otherwise identical with those described under Case 1.

Case 3. In this station the centrifugal pump is eliminated from all operations, only the reciprocating pump being used.

Normal starting and stopping operations are performed from the same causes and by the same means as described under Case 1.

In the section covering mechanical equipment, a detailed explanation is given of the equipment required to protect reciprocating-pump stations against broken pipe lines. A description of the electrical equipment follows. It must be understood that this is a fully automatic station, without operators; hence a different type of equipment is required from that used in stations where operators start the pumps, and the protection required is semi-automatic.

As explained in a previous paragraph, a break in a pipe line operated by reciprocating pumps causes a very rapid drop in pressure; hence successful protection may be accomplished by means of pressure gages.

This protective equipment consists of two pressure gages with scales corresponding to the normal line pressure, each having two electrical contacts and two relays, one of which latter is hand reset. This equipment is illustrated in Fig. 6. When the automatic station is first started, the pressure of the discharge side of the pump is zero. In order to prevent the tendency of the motor to shut down by low pressure before the station is started, two pressure gages are necessary, one of which is called the "setting" gage and the other the " tripping" gage. The operation of these gages is as follows: The high-pressure contact point of the "setting" gage is adjusted to the normal line pressure of the pipe line. When pressure is established on the discharge side of the pump, the needle making contact with this setting energizes the



FIG. 9 MOTOR-OPERATED GATE VALVES

coil of a relay, which, when closed, connects the electrical contacts of the "tripping" gage. Then if while the pump is running there should be a break in the pipe line, the needle of the "tripping" gage makes contact with the low-pressure setting, energizing the coil of a time-limit hand-reset relay, which opens the holding-coil circuit of the motor control, stopping the motor and closing the electrically operated valves on suction and discharge, and at the same time closing an alarm circuit notifying the pipe line office, some distance away, that trouble has occurred. A time-delay relay is used, as it is found that in starting a reciprocating pump there is a tendency for the pressure to build up and then to drop back to a low point for a few seconds, finally establishing the operating pressure. If an instantaneous operating relay were used, the motor would be stopped during this period of momentary low pressure. In case of a plugged pipe line or the closing of a valve on the discharge side of the pump, the needle of the "tripping" gage would make contact with the high-pressure setting terminal, operate the time relay, and stop the motor and pump as outlined.

A hand-reset relay is used to prevent restarting of the pump and motor.

MASTER CONTROL SYSTEM

The pump station described in this paper is fully automatic, capable of taking care of every emergency condition which might arise, and to fully protect all of the equipment. However, pipe-line engineers and superintendents have definitely decided that it is necessary for an operator at some point to be fully conversant with the conditions which exist in these automatic stations, so that in case of line breakage or trouble having developed in the machinery, repair crews could be dispatched immediately.



FIG. 10 FLOWMETER *FM*-2 ON DELIVERY END OF PIPE LINE

This master control system has therefore been designed to fulfil the requirements outlined and to supplement the automatic operation of pipe-line pumping stations.

Briefly, this system, used in conjunction with any two-wire telephone circuit, serves to signal from the automatic station to the central control point the exact conditions which exist as regards open or closed valves, stopped or running pumps, hot bearings, etc., and to enable the operator at the central control point to have complete control over the operation of the equipments at the automatic stations. A summary of the operations to be performed by the master control system is as follows:

To be signaled from automatic station to central control point:

(1) Open or closed position of all motor-operated valves
(2) Running or stopped motor-pump units
(3) Electric power "on" or "off"
(4) Temperature of pump or motor bearings when reaching a predetermined maximum value
(5) Pump-room temperature when reaching a predetermined maximum value (indicating a fire)
(6) Station shutdown due to loss of suction pressure
(7) Station shutdown due to excessive flow of fluid through pipe line (indicating broken line in reciprocating-pump station
(9) Indication of normal suction pressure
(10) Indication of normal discharge pressure
(11) Additional indications may be provided to meet operating conditions.

Control which may be provided from central control point to automatic station:

(1) Opening and closing of motor-operated valves
(2) Starting and stopping of motor-pump units
(3) Opening and closing of main electric service switch
(4) Listening-in connection for telephone in pump room of automatic station, enabling operator to hear what is taking place
(5) Repeater service, enabling operator to have repeated a signal which was not received satisfactorily
(6) Any automatic operation at the pump station may be directly controlled by means of the master control system.

Method of Operation

This control is accomplished by means of impulse switches operating impulse relays in conjunction with polarized, lockout,

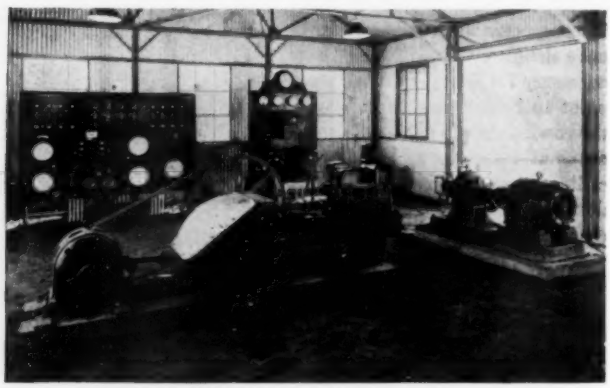


Fig. 11 Inside View of Automatic Pumping Station

and interconnecting relays. Signaling from the automatic station to the central control point is accomplished by means of a small motor driving through reduction gears, rotating the impulse switches, all of which with the exception of the operation to be signaled, are "locked out" of the electrical circuit.

A pair of telephone wires, preferably copper, serve as the electrical connections between the automatic station and the central control point. Seventy-eight operations may be dispatched over these two wires in either direction, and a signal may be sent in both directions at the same time without interference.

Control Switchboards

The control panel at the central control point consists of a metal etching mounted on an ebony asbestos panel representing an actual picture of the equipment and arrangement in the automatic station. The piping, valves, pumps, motors, etc., are shown in their actual relations to each other; red and green signal lights are located directly above the equipment the condition of which is to be indicated, and control switches are located directly below the equipments to be operated. This is all shown in Fig. 4. Thus the operator at the central control point, by glancing at this panel, knows the actual condition of all the equipments, and if any dangerous condition arises, such as a hot bearing, an alarm is sounded, in addition to the turning on of a red light.

The instrument board at the automatic station contains the thermal indicators, flowmeter, pressure gages, and other instruments and various types of relays used in connection with the master control system.

Electrical energy is supplied from 130-volt batteries, and either primary cells or storage batteries may be used.

Actual tests have been made proving that signals may be successfully transmitted over an equivalent of 800 miles of No. 8 (B. & S. gage) copper wire, simplex and phantom circuits, and with a high-resistance ground connection to the circuit.

Experiments are being conducted in connection with the use of a gas indicator device to signal the condition of an oil leak in the automatic pump station, the accurate gaging of tanks from distant points, and the transmission of pressure readings from that automatic station to the central control point.

It is always difficult to sustain a reader's interest in a detailed technical description. In entering into the details of the Tulsa station, we have done so realizing that the pipe-line industry is seriously interested in these experiments, and if the details have lessened the readability of this paper, we trust that it may be pardoned for that reason. In closing, we wish to point out that the work described has only been in progress twelve months, and while the A.S.M.E. Special Research Committee on Automatic Pipe-Line Pumping Stations feels that much has been accomplished, there is yet a great deal to be done.

One of the penalties accompanying the use of automatic equipment of any sort is the occasional failure of some minor part which interrupts the whole system. The only solution for such failures is continual improvement of the failing parts, until they are as serviceable as all other parts. There are doubtless a number of weak links in the Tulsa station which would develop failure only after actual continuous operation in a pumping line. Further application of this system to main lines, with a corresponding development of the equipment, is here suggested, and it is the expectation of this committee to continue this work. There are at this time two major pipe lines using parts of this system on their loops.

There are still two other branches of the pipe-line industry which have not been touched in these experiments, but which can be improved by automatic operation, and they are the pipe-line transportation of refined gasoline and the piping of natural gas from the Mid-Continent gas fields to the Eastern and Northern centers of population. The natural-gas pipe lines are becoming one of the nation's important public utilities, and it is already evident that pure competition and the necessity for reducing the cost of piped natural gas are going to force the natural-gas companies to automatic operation. We will leave the subject here. It has been said that no good work is ever fully completed, and that is true in this case. If we have left with those who are connected with the oil and natural-gas industries a desire to carry on these efforts in their own organizations or in collaboration with this A.S.M.E. committee, our efforts will have been amply rewarded.

PET-52-2

Lubrication of Power Cylinder of Diesel Engines and Causes of Cylinder Wear

By J. B. HARSHMAN[1] and JOHN M. McGREGOR,[2] TULSA, OKLA.

To determine methods of reducing Diesel cylinder-liner wear and to establish reasons for great differences in the rate of wear, a series of tests and experiments, extending over a period of four years, were carried out by the authors. The cost of the renewal of liners on a large pipe-line system is very considerable, but it is only a portion of the total losses. Added to liner-renewal expenses are the troubles likely to accrue from contamination of the oil in the crankcase, from loss of power, etc., which add greatly to operating costs.

In this paper the authors attempt to show how liner life may be lengthened with a resulting greater economy in the operation of the Diesel engine. Methods adopted for applying the cylinder oil and other causes allied to poor lubrication are discussed. The tables in the paper show what can be effected by changing the grade of oil in use and by correct treatment of fuel oil and the air.

SUCCESSFUL operation of a Diesel engine depends largely upon how efficiently it is lubricated. There are a number of factors, other than lubrication, that must be considered before the best of lubricants can give satisfactory service. After careful thought and many tests the authors are forced to the conclusion that many important details have been overlooked by the majority of engine manufacturers, and they will try to show some of the means that might be adopted to give better economy and better service when operating oil engines, whether they be used on pipe lines or other service.

Method of Checking Cylinders

To determine the rate of wear in liners a system of checking was adopted and standardized throughout the entire system. No matter what method be used it must be such that it is simple yet at the same time accurate, otherwise the results secured will be useless. The manner in which checks were made is as follows:

Starting at the flywheel side of the cylinder and directly above the crankshaft a mark is made on the top face of the liner and called zero deg. The liner face is measured carefully every 45 deg. and is marked with a center punch; these points are called 45, 90, and 135 deg.

In order that the micrometers may be located exactly at the same point each time a T-square is used. This consists of a piece of $1\frac{1}{2}$ in. angle iron about 15 in. long, riveted or brazed to which is a strip of metal 1 in. by $\frac{1}{4}$ in. A series of holes are drilled in the strip, the top of which registers with the center of the top ring when the piston is at its inner position. A punch mark is made on the angle iron so that, when it is laid across the top of the liner, this mark will register with the marks made on the liner face. Other holes can be drilled in the metal strip, the position of these depending on the length of stroke and type of engine. During the tests holes were drilled every inch down from the top hole, and measurements were usually taken for the top 6 in. of the cylinder, and at the four points previously named. With certain engines, however, it was thought necessary to go further down; this would apply more to two-cycle engines such as that used in this example. In passing it might be noted that the results of the checks show that, whereas the majority of two-cycle engines wear to what might be termed barrel-shape, the four-cycle engine wears in the form of a taper with the largest diameters at the top.

In order to make the checks the T-square is laid into the cylinder with the angle iron resting on top of the liner and the strip with the holes hanging down inside. The mark on the angle iron is brought into line with the several marks on top of the liner and the measurements are taken by placing the point of the micrometers in the drilled holes. By adopting this, or some similar method, it can be readily seen that no matter what time elapses between checks one can always be sure of going to exactly the same point. This is essential, as a difference as great as 0.012 in. has been found by moving the micrometer round the cylinder wall only 15 deg.

In submitting the following tables showing actual measurements made on a 17-in. by 25-in. two-cycle engine, it should be explained that much work was carried out on engines of this type as liner life was extremely short. The stars opposite some of the figures denote the point of greatest wear in each case, and it is this point that is taken to determine the rate of wear, for should it be necessary to bore out the cylinder it is to this point that one would have to work to make a correct job.

A log is kept for each engine, and the hours it runs is noted and brought up to date each day. The total number of hours the engine or liner has run is divided by the greatest wear and the result listed as so many hours run for every 0.001 in. wear.

In making checks the same micrometers should be used on the same engine as considerable discrepancy has been found to exist on different instruments, and further, the cylinders should be at, or near, the same temperature each time a check is made.

Grade and Quantity of Lubricating Oil

The proper grade and quantity of lubricating oil to be used is of primary importance. The authors recently carried out a series of tests on different oils and found that the difference in results was surprising. It is an extremely difficult matter to state just what kind of oil or how much should be admitted to the cylinder, but to a large extent successful lubrication will depend on these determinations.

As conditions vary so much in different types and sizes of engines there will be no attempt made to lay down any hard and fast rule. It has been found over a large number of units that practically each condition must be studied from its own particular viewpoint. It has been found frequently that by a change from a light grade of oil to a heavy grade, or vice versa, the liner and ring life can be materially increased.

Choice of the correct oil is doubtless the leading factor in proper lubrication. Most reputable oil companies manufacture oils that will give satisfactory service, but it has been found

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Presented at the National Petroleum Meeting, Tulsa, Okla., Oct. 6 to 8, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

that even they are sometimes liable to err. Cases have been found where a change from an accepted standard brand of oil to a new oil made by the same company resulted in very considerable improvement. This was done when making the tests, the results of which are shown in accompanying tables. It is impossible to state how much a cylinder will require; even cylinders of the same size will vary in the correct consumption, and this can only be determined by the men responsible.

Method of Application

The method of application of the cylinder oil appears to have been given insufficient attention by the engine builders. The

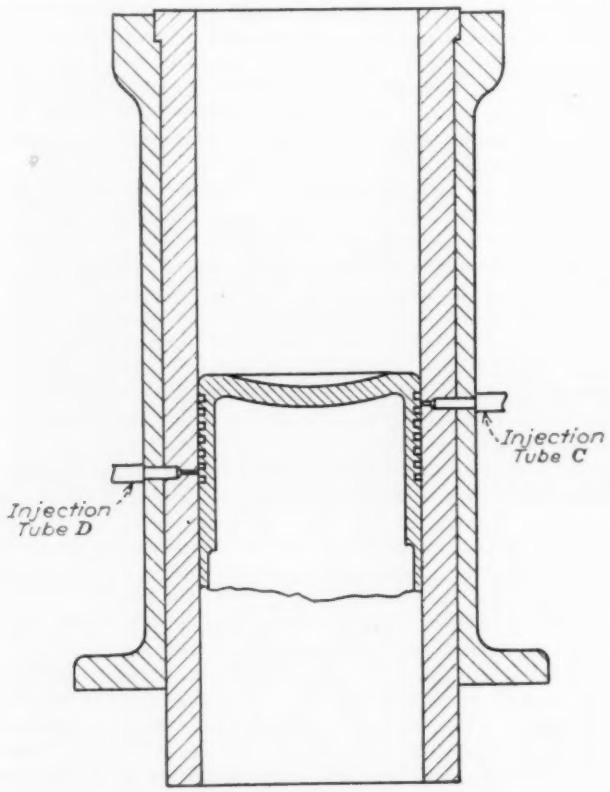


Fig. 1 View of Cylinder
(Showing correct and incorrect methods of locating injection tubes in relation to piston rings with piston at lower end of travel.)

piping system and position of the points of entry of the oil-injection tubes vary according to the opinion of the average manufacturer or it might even be said of some cases that the lubricating system has been added to the unit without any consideration of its importance. That the position varies greatly can be seen from the fact that in some cases the oil enters at a point registering with the bottom of the piston rings, and in others even ahead of the top ring when the piston is on outer center. This is illustrated at *D*, Fig. 1.

It has been found that the ideal position for the point of entry of the oil is between the first and second rings counting from the head end of the piston, as shown at *C*, Fig. 1. The injection tube should be of such a type that the end discharging the oil will extend through the liner to the inner wall, and should have a valve or some form of restrictor as near the inner side of the liner as possible. A tube of this type is illustrated in Fig. 2.

By so doing the oil will be prevented from dribbling and the suction of the piston will not have the same tendency to whip the oil from the tube when the piston rings travel over the end of the oil tube. With this continual whipping or dribbling action, the majority of the oil is pulled out on to the piston skirt with the result that the parts most requiring lubrication are more or less totally ignored.

The open-type injection tube so commonly used is very undesirable as it permits the hot gases from the cylinder to enter the tube, and, coming in contact with the oil, renders it practically useless from the point of view of lubrication. It has been found that where the open-type injection tube is fitted, the check valve, if any be fitted, being well outside the cylinder, the oil is changed from a good clean lubricant to a contaminated oil. Fig. 3 shows such a type of tube. Samples have been collected and have been found to be extremely dark in color, and a great deal higher in viscosity than the oil in the mechanical lubricator.

Table 4 shows the characteristics of two new oils as supplied to the lubricator. Samples of each of these oils were drained from the feed lines leading from lubricator to cylinder. Tables 5 and 6 are presented to show the decomposition of the oils after coming into contact with the hot gases blown back from the cylinder into injection tubes and feed lines. Table 5 is analysis of oil No. 1 and Table 6 is analysis of oil No. 2. This experimental work was done by Mr. W. O. Northcutt and was presented in a paper read at the regional meeting of the A.S.M.E. held in Kansas City, April, 1927.

Further, entrance of hot gases to the oil lines carbonizes the oil, and will have a tendency to block some of them completely should the piping system be composed of branch lines coming from one line from the lubricator, as shown in Fig. 4.

Reference to Tables 1 and 2 will show that the improvement is very marked. During the period covered between the two checks a different brand of oil was used. In the original installation a lubricator was fitted on top of the cylinders and two feeds were supplied to each cylinder, each feed being split through a tee giving four points of entry for the oil. However,

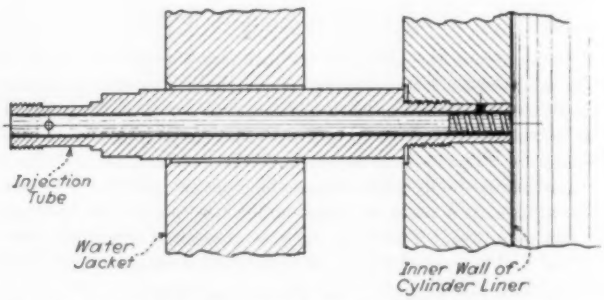


Fig. 2 View of Injection Tube to Power Cylinder
(Fitted with restrictor at inner wall of cylinder liner.)

it has been found that neither of these conditions can give good lubrication. The lubricator should be placed below the point of entry of the oil and each point of entry of the oil should have a feed direct from the lubricator, as illustrated in Fig. 5. If this be done the difficulty of lines becoming blocked with carbon will be overcome. It is further suggested that all cylinders of 75 hp. and over should have four individual feeds direct from the lubricator to the cylinder.

With a lubricator mounted on top of the engine and with faulty check valves, and these are far from being rare, the lines are very likely to be drained of oil whenever the engine is shut down. It has been noted that after the engine has been shut down for a considerable time it requires several minutes of hand priming to fill the line. Were the unit to be started up without

priming and completely filling the lines, piston seizure or excessive wear would very likely take place.

Many engines are equipped with lubricators of an obsolete type that pump a great amount of air with the oil; this results in pockets of air being formed in the lines. The air is forced through at varying intervals, sometimes two or three minutes apart, and carries a quantity of oil with it leaving several inches of the line empty of oil. Tests on engines equipped with lubricators of this type have shown that in engines of 24-in. stroke and running at 200 r.p.m. more than 2 miles are frequently covered by the piston before it receives a fresh supply of oil. A lubricator that will pump oil free from air will overcome this difficulty.

Effect of Piston-Ring Pressures and Design

The type of piston ring used in an engine is a very important factor in the life of the cylinder liner. Excessive ring pressures increase the amount of liner wear greatly. This point is readily noted by referring to Table 2 and examining the difference between the wear in cylinder No. 1 and that in the other three cylinders. As was noted at the foot of the table, a new type of ring was tried out in cylinder No. 1 and the old rings were left in position in the other three cylinders. The rings tried were $^1/_4$ in. wide, and the average wear was such that the liner life equaled only 170 hr. per 0.001 in. wear against the average for the other three cylinders of 904 hr. In the cylinders giving the long average wear, rings $^1/_4$ in. wide were used. The narrow rings were tried with a radial thickness of three different sizes, but with no better results. A wide ring with the radial thickness of approximately two-thirds the width gave the best results.

In order that observations might be made regarding the conditions under which rings had to operate a cylinder of 17-in. bore was accurately measured every 15 deg., and the results are shown in Table 3. The measurements were taken at points registering with the middle of the top ring when it was at the inner end of its travel. Despite the short space between the points that were checked, the difference in wear is considerable

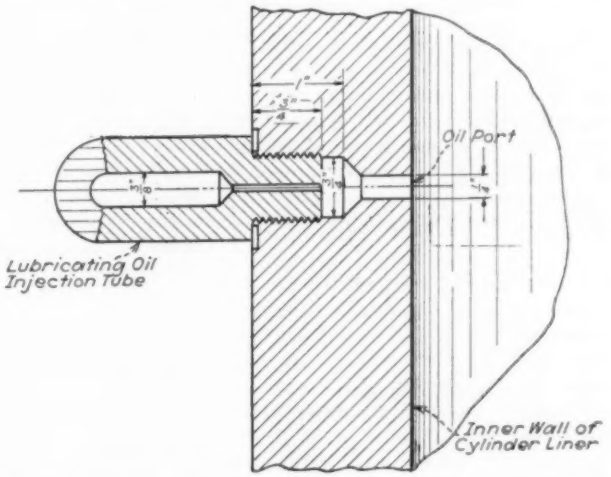


Fig. 3 Sectional View of Cylinder Liner and Injection Tube
(Showing open pocket at inner end of injection tube.)

in some instances. With new or stiff rings especially, and considering the shape of the liner to which the ring is supposed to conform, it is not surprising that there is considerable leakage. Theoretically, the ring is supposed to act as a seal for the gases by pressing against the wall of the cylinder, but it would appear that such a condition is nearly impossible. In fact, it seems reasonable that instead of the gases assisting the rings to form

TABLE 1 CYLINDER MEASUREMENTS

		Cylinder 1 Degrees				Cylinder 2 Degrees				Cylinder 3 Degrees				Cylinder 4 Degrees			
		0	45	90	135	0	45	90	135	0	45	90	135	0	45	90	135
Top		620	630	660	640	600	570	740	760	700	640	700	725	660	660	650	635
1 in.	Down	630	660	630	700	640	680	740	820	725	660	720	800	700	665	670	725
2 in.	Down	760	720	665	740	745	680	690	800	830	720	730	850	800	670	680	750
3 in.	Down	830	720	730	800	800	675	650	785	870	760	750	840	850	685	685	750
4 in.	Down	*850	720	750	845	840	715	680	780	*890	760	730	830	*855	740	700	770
5 in.	Down	820	680	710	840	*850	755	710	780	885	730	710	800	820	720	680	745
6 in.	Down	770	630	640	770	805	740	690	750	840	700	665	730	760	650	620	685
8 in.	Down	630	500	460	580	680	610	590	610	700	580	530	560	610	490	470	525
Top	Port	210	270	220	260	270	280	290	300	210	270	210	190	260	240	200	265
Bottom	Port	140	130	100	120	200	130	140	170	140	120	100	120	190	120	100	120
Cylinder temperature, deg. fahr.			65				70				66				64		
Hours run			13,335														
Hours run per 0.001 in. wear			157				157				150				156		
Average of all four cylinders			155														

Measurements are in inches omitting the 17 and the first decimal place which is zero. For example, the first measurement would read 17.0620 in.

* Points of greatest wear in each cylinder. Note: Table 1 shows total wear and hours run from time engine was installed.

TABLE 2 CYLINDER MEASUREMENTS

		Cylinder 1 Degrees				Cylinder 2 Degrees				Cylinder 3 Degrees				Cylinder 4 Degrees			
		0	45	90	135	0	45	90	135	0	45	90	135	0	45	90	135
Top		600	670	705	710	555	625	740	820	730	730	780	930	590	665	665	665
1 in.	Down	1000	835	870	1035	710	680	725	835	920	730	760	950	580	660	685	660
2 in.	Down	*1080	925	880	1035	795	670	650	825	945	805	800	940	870	695	680	790
3 in.	Down	1035	915	905	1035	830	700	645	820	950	865	800	915	890	745	730	810
4 in.	Down	1020	905	910	1035	*875	760	685	830	*980	850	780	930	*910	810	750	840
5 in.	Down	980	855	855	990	*875	800	715	630	955	820	760	890	890	810	730	810
6 in.	Down	925	785	780	920	860	780	690	800	915	775	710	820	840	730	665	745
8 in.	Down	760	630	600	750	735	655	580	680	779	630	560	650	685	550	505	585
Top	Port	205	270	245	270	270	290	270	320	180	245	170	175	220	200	150	210
Cylinder temperature, deg. fahr.			66				69				68				66		
Hours run since last check			3917														
Hours run per four cylinders			721														
Average of cylinders 2, 3, 4			904														

* Points of greatest wear in each cylinder. Note: The wear in cylinder No. 1 was not reduced materially due to the fact that experiments were being made with a different type ring. In the other cases, rings were the same as in previous check.

TABLE 3 CYLINDER MEASUREMENTS TAKEN AT TOP EVERY 15 DEG.

Degrees	0	15	30	45	60	75	90	105	120	135	150	165
Top	795	690	650	620	660	685	655	625	620	600	695	175

a seal by pressing behind them they will have a tendency to press on the face of the ring and further accentuate the loss of power due to leakage.

Abrasive Material in Intake Air

The subject of lubrication covers a very wide field and it must be considered from several points. The intake air and the fuel oil have each a bearing on the matter. In passing, it is desirable to point out that no matter what type or quantity of lubricating oil be used it cannot give satisfactory service unless all other points are considered, and when difficulties are encountered that they be dealt with. The cleaning of air is one essential. The modern automobile manufacturer attempts to eliminate, as far as possible, entry of abrasive material into the motor. Air filters are just as essential on a Diesel engine as on an automobile, especially when a plant is in a dusty vicinity. Naturally, engines of different designs and sizes take different quantities of air. However, the ratio of the foreign matter to the total quantity of air under similar circumstances will be the same. From one to four grains of dust are found in every 1000 cu. ft. of what is considered fairly pure air. With a displacement of 2000 cu. ft. per min. a unit would draw in from $1^1/_2$ to 6 lb. of dust every week. Such a quantity of dust should be eliminated, for any considerable amount entering the cylinder is likely to mix with the lubricating oil and make the latter a first-class abrasive instead of a first-class lubricant as it was intended to be.

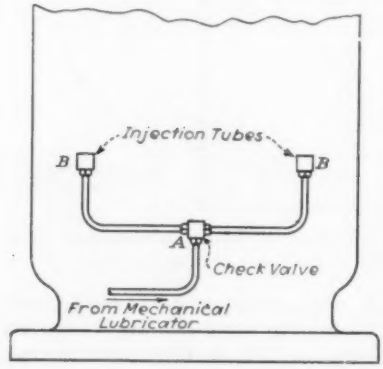


Fig. 4 View of Piping to Power Cylinder
(Showing one line from mechanical lubricator and branching at check valve *A* to two points on cylinder at injection tubes *B*.)

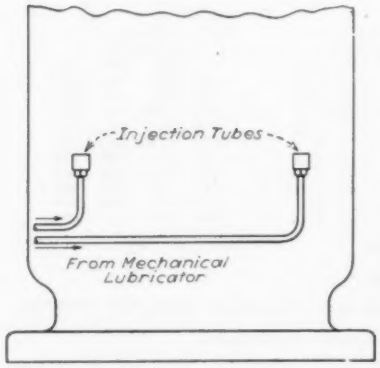


Fig. 5 View of Piping of Power Cylinder
(Showing two separate lines from mechanical lubricator to lubricating-oil injection tube.)

Abrasive Material in the Fuel Oil

It appears that one should reasonably expect to get a fairly clean fuel no matter from what source it may be obtained. Yet, all contain a certain amount of foreign matter, much of which would act as a cutting compound if it were permitted to enter the cylinder. It is not alone the liners and rings that suffer, but probably as great if not greater damage will be done to such parts as fuel-pump plungers, injection valves, etc., where an oil containing a considerable percentage of solid matter is used without cleaning it in some effective matter. Extensive tests have shown that no matter what fuel be purchased, care should always be taken to see that it is cleaned either by heating and settling or by the use of a centrifugal machine.

TABLE 4

	Flash	Fire	Viscosity at 100° F.	Viscosity at 210° F.
Oil No. 1	410	460	410	57
Oil No. 2	410	470	398	55

TABLE 5 OIL NO. 1

Flash	Fire	Viscosity at 100° F.	Viscosity at 210° F.
410	470	482	62
Acidity			0.560
Total sediment, per cent			0.074
Analysis of total sediment:			
Asphaltic matter, per cent			0.300
Carbonaceous matter, per cent			0.365
Ash, per cent			0.075

TABLE 6 OIL NO. 2

Flash	Fire	Viscosity at 100° F.	Viscosity at 210° F.
410	465	466	60
Analysis of total sediment:			
Asphaltic matter, per cent			0.140
Carbonaceous matter, per cent			0.218
Ash, per cent			0.062

There is a machine for almost any size of installation and although the first cost may be considered high it is believed that such an installation will pay for itself in a very short space of time. The use of the centrifugal machine is being more and more adopted in pipe-line systems and so far the authors have never been able to find an instance where the centrifugal machine has not proved its worth. After passing the fuel oil through the centrifuge it is practically cleared of all solid matter and all water is removed. Ash content is almost entirely eliminated and the sulphur content may be considerably decreased in some instances. The flash point of the fuel is raised and the calorific value is increased considerably. Mysterious pitting on the surfaces of the metal in the unit may often be traced to the presence of sulphur in the fuel. It is questionable whether any appreciable amount of the sulphur can be removed by centrifuging; there are some who maintain it can, and some who maintain it cannot. However, if it can be, so much the better argument in favor of the adoption of the centrifuge machine, more especially when engines are stopped and started frequently, giving rise to the almost inevitable presence of moisture. Fuel oil with a high sulphur content, unless it can be cleaned perfectly, should be avoided as the sulphur burns, forming sulphur dioxide, which, reacting with any water that may be present, will form an acid and give rise to a condition frequently blamed on poor lubrication.

There is no doubt that the amount of foreign matter in fuel varies greatly, but figures taken from a number of main-line stations give an average of one pound of solid matter removed from every five barrels of fuel treated by means of a centrifugal machine.

Instances have been noted where, by the introduction of treating methods for the fuel, the liner life was lengthened by more than twice and also valve grinding and valve renewal, pump plunger replacement, etc., were very considerably lessened. The introduction of such an accessory need not prove expensive nor need the arrangement be complicated, and should soon pay its way. At first sight it might appear that air filtration and fuel-oil cleaning have no bearing on the subject, but the introduction of dirt with the air or with the fuel oil will readily multiply any efforts made to secure perfect lubrication. Space does not permit discussion of other points such as design and cleanliness of water jackets, misalignment of parts, and poor metal, but all enter into the question of liner life, and often are the real causes of poor lubrication.

Conclusion

The authors have attempted to describe the more important

conditions affecting the lubrication and life of power cylinders of Diesel engines. From their observations the causes of excessive cylinder wear are in most cases a combination of several of the aforementioned conditions, and it is suggested that the purchasers of a Diesel engine would do well to present specifications to the manufacturer demanding that the engine to be purchased be equipped with lubricators that will not pump air and that they be mounted below the cylinders, pumping upward, and supplying oil to each point of application to the cylinders through an independent line from lubricator to injection tube.

The injection tube should be of a type that will prevent the blowback of hot gases from the cylinder into the tube and not permit the suction of the piston to draw the oil out of the lines. The injection tube should be located preferably between the first and second rings from top of piston and not lower than between the second and third rings when the piston is at bottom.

Discussion

A. E. Flowers.[3] The paper shows evidence of a carefully planned, well-conducted, and thoroughly reported investigation. The results are well represented by the tables and illustrations shown.

It is to be hoped that the authors will have added to the sketch of the lubricating-oil injection tube, shown in Fig. 3, a line sketch showing the location and type of check valve they have found suitable in avoiding burning oil left in the tube by the hot gases.

It is stated that Tables 1 and 2 show the wear results upon change of oil, but it appears that the method of feeding oil was also changed. It would be well if the authors would clarify these statements, for if both conditions were changed simultaneously, there is little basis for proof that one oil was better than the other. It would be helpful if the authors would give the full set of physical tests of each oil used and state in the heading of Tables 1 and 2 which was used during each test.

It is suggested that in Fig. 1, showing the proper and improper location of lubricating oil tubes, the words "Improper Location" be inserted under the words "Injection Tube D" and the words "Proper Location" be inserted under the words "Injection Tube C."

For some reason Table 6 does not include test values for acidity and for total sediment, as Table 5 does, so that the comparison is not as complete as the authors intended it to be. Headings for Tables 5 and 6 might well be added stating Oil No. 1 and Oil No. 2, respectively, and the words "Samples Collected From the Ends of Lubrication Tubes," to show at a glance the character of the material.

The authors' observations on the reduction of wear as a result of centrifugal purification of the fuel oil agree with the statement made by Mr. L. R. Ford in his paper last year before the A.S.M.E. meeting at State College, Pennsylvania, in regard to marine Diesel engines.

The authors' observations of the effect of sulphur are interesting, as well as the possible effect of centrifuging. It is well known that free sulphur dissolves in oil and while dissolved cannot be centrifuged out, but there seems to be a special affinity between such free sulphur and metal or other particles, so that the sludge collected in a centrifuge bowl will show a higher sulphur content than the oil. It is possible that sulphonated compounds are present in oils which would separate or stay with the oil depending upon whether they were in solution or present as pitchy, semi-solid, heavy compounds, as the latter could be removed by centrifuging.

[3] Engineer in Charge of Development, De Laval Separator Company, Poughkeepsie, N. Y. Mem. A.S.M.E.

E. H. Hillman.[4] The authors have presented many useful points which should be of value to Diesel-engine builders and operators. Their comments on the position of the lubricator and the need for separate feeds to each point are particularly valuable. The writer has noted several instances where one of the two split feeds from the same lubricator pump was stopped up after comparatively short runs. It is only natural that this would occur when it is considered that the same amount of oil will not be pumped through each injection tube. The tube receiving the least oil will naturally choke up somewhat faster, and this choking will still further reduce the feed, which in turn will permit a faster accumulation of deposits. On the other hand, all the oil which does not go out of the partially choked tube will go out of the other tube, which thus will be swept clean of all deposits. It may be doubted, however, that four individual feeds are necessary except for large engines.

The data on deterioration of cylinder oil, due to blow-back of hot gasses into the lubricator tubes, should be of interest to check-valve manufacturers; but this blow-back would not necessarily make the oil unfit for use. It is obvious that such blow-back, when it occurs, will not subject the oil to such severe conditions as it will find on the cylinder walls and rings, where it will come in contact with gases which have not been appreciably cooled. An oil which will lubricate the cylinders satisfactorily could hardly be deteriorated to a dangerous extent by gases blowing into the lubricator tubes.

The rate-of-wear data point to a branch of Diesel lubrication which has been inadequately studied. The effect of viscosity and other variables should be determined separately. If this were done, it is suggested that a regular change in rate of wear with change in viscosity would be found, the rate being different, of course, for different engine types and operating conditions.

The authors suggest that cylinder wear be measured by comparing only the points of greatest wear. This method will show the effect of mechanical irregularities, such as misfitting rings, irregular liners, or piston slap which might cause a great deal of wear at certain points during one inspection period, but little wear during the next period.

In any study of cylinder wear, one is of course primarily interested in the effect of conditions such as load, temperature, design, or lubrication, which will cause substantially uniform wear. One is not interested in mechanical misadjustments which might cause localized wear or scoring, except to know that they exist, and to effect a remedy if possible.

Thus in comparing the wear obtained with different types of rings or with different lubricants, it is suggested that always the average wear be determined. All measurements taken on the upper part of the cylinder covered by the ring travel should be averaged at the start of the test and at the end of the test. The difference will give a much clearer picture of the rate at which wear is taking place, and will normally show less wear than that obtained by the maximum diameter method. If all the top nine measurements in Table 1 are averaged and compared with a similar average for Table 2, the hours per 0.001 in. wear will be 884 instead of 721, as shown. The rate of wear by the average method will naturally be slower than by the maximum diameter method, since it minimizes localized excessive wear due to mechanical difficulties. It might even occur in some instances that no wear would be shown when comparing maximum diameters, since a broken ring or other mechanical defect might cause severe scoring at one point which would remain the maximum diameter during several inspections.

While it may be admitted that a determination of the maximum diameter will show the machine shop the size to which the cyl-

[4] Standard Oil Company, Chicago, Ill.

inder liner should be rebored, yet it would appear to have no bearing on a comparative study of Diesel-engine designs or lubricants.

The writer has had the privilege of working with the authors in making cylinder-diameter measurements as described in their paper, and has found them to be accurate and necessary for reliable results. In his own paper the writer has presented data showing the great extent to which diameters may vary from one point to another in the cylinder. This shows the necessity for a method to accurately standardize the points at which measurements are taken.

FRED THILENIUS.[5] Having known both the authors of this paper for some time and having discussed with them many times the points involved, it is easy to agree with them on all of the arguments put forth. It happens that, as assistant master mechanic of the Prairie Pipe Line Company for five years and as superintendent of that company's Panhandle line for three years, the writer was able to collect much of information on the operation of Diesel engines. This information includes several thousand measurements of liner wear taken over long periods, and the results obtained agree very closely with the points brought out in the paper. The writer is pleased, therefore, to confirm several points with additional information and stress a few other points with additional arguments.

On the pipe line mentioned, accurate measurements over a period of six years were recorded to obtain the liner wear for every Diesel-engine cylinder on the main line which included two- to six-cylinder engines in horsepower of 300 to 665 per engine and which involved several hundred cylinders. Measurements were made exactly as described, except that only two measurements were taken, at two positions on each liner. The first position was at the top of the top ring travel and the second was at the half-stroke position of the top ring, and in each case one measurement was taken parallel with and the other at right-angles with the crankshaft. As pointed out it was difficult to obtain accurate measurements without an instrument similar to the one described for a guide, and as mentioned it was found absolutely necessary to use the same micrometer on the same liner each time. Even with these precautions, it was found necessary to check the results obtained at each reading with several other readings over long periods to secure a true indication of what the wear was per thousand hours, for it often happened that a liner would show several thousands of negative wear over a period of several months, due probably to the different temperatures of the liners and micrometers.

It is interesting to note that the measurements shown in Tables 1, 2, and 3 are exactly like 90 per cent of the measurements obtained on the Prairie system in that the zero positions are from 10 to 20 thousandths greater than the 90-deg. positions. This indicates that liners wear more in the direction of the length of the crankshaft than crosswise, and this condition maintains with horizontal trunk-type piston engines as well as verticals. This is interesting because it is generally thought that the side thrust of the connecting rod has much to do with liner wear. At least it was argued by the first vertical-engine builders that the liner wear would be a great deal less than in a horizontal engine, for in the vertical engine the weight of the piston was not carried on the liner. This condition indicates that the forces acting on the liner due to end play of the shaft or misalignment of the connecting rods is as a rule greater than those caused by the side thrust of the rod or the weight of the piston. And this is another point that the manufacturers should take into consideration in the design of their engines. There have been cases where this difference was as much as 50 or 60 thousandths.

As for the application of the lubricating oil to the cylinders it is also the writer's belief that too little thought has been given to this important feature by the manufacturers. It is almost inconceivable that a designer should expect a drop of lubricating oil to have enough intelligence to split itself exactly in half when it comes to a tee in the line as pictured in Fig. 4. And he heartily agrees that a dependable check valve located on the inner end of the injection tube is an essential thing. The writer has disconnected many lubricating lines between the lubricator and the cylinder on engines that had no check valves or faulty check valves and has found the lines full of particles of carbon, as far back as the lubricator. The presence of this carbon in the line is not nearly as important as the condition it indicates. It could only get there by blowing back, which could only happen when the line was partly empty. With no check valve on the end of the line, the oil can run out into the cylinders in slugs, which leaves the line empty until the lubricator can again fill it. With the injection tubes 8 or 9 in. long and bored out to $^1/_4$ in. it is possible for several thimblefuls of oil to run out at one time, and with the lubricator feeding only 4 to 6 drops a minute, there might easily be periods of 15 or 20 minutes during which the piston received no oil at all. This is possible when the lubricator is located at a lower elevation than the injector tubes. When the lubricator is above the tubes, the entire line can drain, and unless it is primed, which is rarely thought of, an engine might run for half an hour after starting without receiving a drop of oil. This condition has been noted many times in the field. Although it is of course essential to have the proper oil for efficient operation and to obtain a minimum amount of liner wear, it can be said that improper application or lack of application at periods accounts for more liner wear than a slight variation of the oil.

As mentioned, it is important to have both clean air and clean fuel, but of these two the fuel seems to be the more important. This is probably due partly to the fact that dust that enters the cylinder through the air is more finely divided and it is dry, and therefore it is more easily carried out again with the exhaust, whereas the grit in the fuel oil is wet and will adhere more readily to the walls of the cylinder and the top of the piston. There is also a much greater quantity of dirt carried into the cylinder by the fuel than by the air. Roughly, each pound of fuel combines with about 15 lb. of air in the cylinder, but there is perhaps twice this amount of air passing through the cylinder. Using the average dirt content given for both air and fuel, this figures that there is roughly 4 lb. of dirt brought into the cylinder by oil for every pound of dirt brought in by the air. This is borne out by the observation that on a large main-line station that was located very close to a cement plant, where the air was thick with dust much of the time, the wear on the liners was found to be only slightly excessive as compared to other stations on the line that were favored with fairly clean air, whereas it was found on another station that the liner wear was cut exactly in half by centrifuging the fuel oil as compared to six other similar stations on the same line using fuel from exactly the same source, even though at the other six stations the fuel was thoroughly settled after heating in twin fuel tanks before it was used on the engines.

[5] Prescott Co., Tulsa, Okla. Mem. A.S.M.E.

PET-52-3

Service Tests on Carbon Formation in Diesel Engines

By E. H. HILLMAN,[1] CHICAGO, ILL.

Testing methods and technique applicable to field conditions are described. Data are presented which have been secured as a result of such tests under service conditions. Laboratory tests designed to measure the carbon-forming tendencies have little relation to results secured in service. At present the only satisfactory proof of merit is service or simulated service tests, but the procurement of reliable data is difficult. Cylinder wear is shown to affect lubrication by preventing proper ring seal.



WHEN a new Diesel engine is placed in operation, the owners and operators are confronted with the task of selecting the lubricants. Most manufacturers of the equipment seldom are in a position to give helpful suggestions. As a matter of policy many hesitate to make specific recommendations and, as a matter of fact, with few exceptions have not run tests sufficient to compare various oils in a quantitative way. They usually offer only the most general specifications or a long list of approved oils without comment as to their respective merits. Heretofore, the refiners also quite generally have not adequately discussed the methods of lubricant selection and the characteristics of suitable oils. The result frequently is considerable doubt among operators as to the factors which should be considered in the selection of lubricants.

Laboratory Tests

Laboratory tests are of limited value for the evaluation of Diesel cylinder oils, the Conradson carbon or carbon-residue test being the only commonly accepted method for measuring the carbon-forming tendencies of an oil in service. Where the same type of lubricating stock and method of refining is used, this test may check up fairly consistently with carbon formation in the engine, but in other instances the results appear to be not at all comparable with engine performance. The operator should therefore place no reliance on this test, since he has no means of knowing the source and methods of refining used on the products offered for purchase. Table 1 shows clearly the lack of relation found between the laboratory test and field results. It would seem that there is no adequate test to show the carbon-forming tendencies other than running in an engine as outlined farther on.

Many factors indirectly affect the cylinder lubricant, such as engine size, speed, type of cycle, combustion characteristics, fuel-injection method, piston-cooling method, cylinder cooling, type of fuel, piston-ring type, and air condition.

Undoubtedly the resultant of these various factors, together with the exact method used in applying oil to the cylinder walls, will for any given operating condition result in a definite oil-film temperature on the cylinders, piston walls, and rings which, if known, would be of major importance in selecting the proper lubricant. Such film temperatures would take into account design factors, operating factors such as load and cooling-water temperature, and condition factors such as ring wear and blow-by.

It would be helpful to know the actual operating temperatures on the lubricated surfaces of Diesel-engine pistons for various conditions. This information should be of great assistance in selecting proper lubricants. Temperatures around the piston rings ranged from about 200 to over 300 deg. fahr. in a few tests made with special equipment to measure temperatures of the oil film at such points.

Unfortunately, we find on the one hand that laboratory tests give an inadequate clew as to the deterioration of oil in service, and on the other hand data on oil film temperatures or their underlying causes are not available in sufficient quantity to work out a lubrication theory or to permit the application of a theory to individual cases. In the study of cylinder-oil deterioration we were therefore restricted to tests under service conditions.

Engine Carbon

Two-stroke-cycle crankcase scavenging engines seem to form carbon more rapidly in the exhaust passages. In all Diesel engines, gumming and sticking of rings causes more or less trouble and loss of time from shutdowns. Since measurable amounts of these deposits form after comparatively short runs, we have been able to work out methods for reliable comparisons of various oils in a comparatively short time.

Carbon deposits are found in two main locations: (*a*) in the exhaust passages and (*b*) around the piston rings. In the first case, they cut down the scavenging efficiency of the engine, and if allowed to accumulate may cause serious loss of power or overheating. The tendency of deposits to form in this location varies to quite a large extent with the design of the engine and is not serious in many cases. In the second case, pistons must be pulled and cleaned more often than would be necessary if carbon deposits around the rings could be avoided. These deposits retard the free action of the rings, with consequent decrease in their sealing efficiency. Eventually they become stuck, especially the top ring, with an even greater loss in efficiency, increased blow-by, and accelerated oil deterioration.

Fig. 1 and Table 1 show how the weight of carbon deposits in exhaust passages of a two-stroke-cycle engine varies for several oils. It will be noted that as the exhaust-gas temperature increases, the weight of deposits decreases. This is undoubtedly due to the fact that higher exhaust-gas temperatures dry out the deposits so that more are blown away by the force of spent gases. The table also shows the viscosity and the carbon residue value of several oils. The lack of correlation is evident.

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[1] Technical Division, Standard Oil Company (Indiana). Mr. Hillman was graduated in chemical engineering from Purdue University in 1923 and shortly afterward entered the employ of his present firm, being assigned to the lubrication department. In recent years his work has been mainly with the development and testing of new lubricating products, especially Diesel oils. He is in charge of this work in the Technical Division of the company.

Presented at the National Petroleum Meeting, Tulsa, Okla., October 6 to 8, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

TABLE 1 OIL RATINGS IN DIESEL TESTS

Deposits in Diesel-Engine Exhaust Passages[1] (From Curves)

Oil	Conradson carbon residue[4]	Viscosity at 210° F.	Exhaust-gas temperatures 420° F. (Grams)	Exhaust-gas temperatures 440° F. (Grams)	Piston order of merit[2]	Oil used, gal. per hr.[3]
A	0.09	65	0.75	0.50	1	0.274
B	0.05	61	1.50	0.80	3	0.264
C	0.32	57	1.80	1.20	5	0.228
D	0.10	56	2.55	1.85	2	0.246
E	0.49	64	2.8	1.90	4	0.235

[1] The figures show the average weights of deposits formed in standardized areas of the exhaust passages of a 240-hp., two-stroke cycle, port-scavenging, four-cylinder Diesel engine, during 55 hours' operation, with the average exhaust temperatures and with lubricating oil as shown.

[2] Based on carbon found back of rings, tightness and oiliness of rings, and general observations of piston and ring condition.

[3] Lubricator feeds were the same in all tests. Reason for variation not known.

[4] Conradson carbon test.

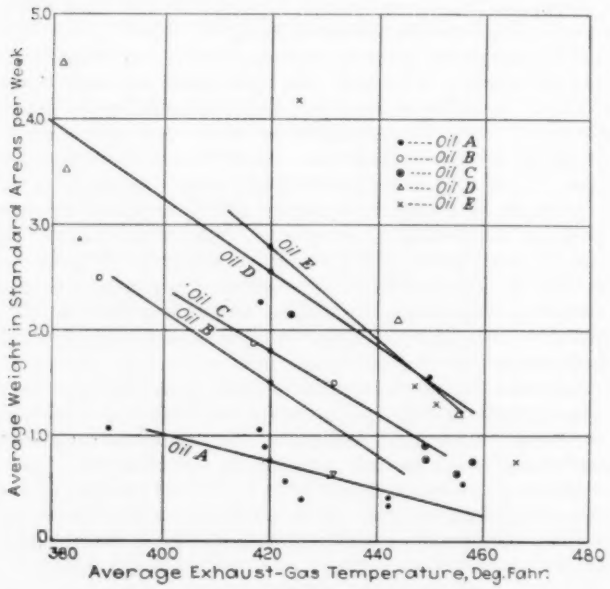


FIG. 1 DEPOSITS IN EXHAUST PASSAGES

(Two-cycle crankcase-compression port-scavenging solid-injection Diesel engine.)

Table 1 also shows ratings based on piston and ring lubrication and ring carbon.

TEST METHODS

During most of these tests, deposit samples were taken from two standardized areas in each exhaust passage each week. Thus, eight samples from the four cylinders in the test engine were averaged to get the carbon-forming tendencies of the oil for the weekly period. Samples as above were compared with the average exhaust-gas temperature for the week. Since the number of hours which the engine operated varied from week to week, it was necessary to correct the weight of deposits to what would have been obtained in a standard week, assuming carbon formation to proceed at a uniform rate.

Tests on the foregoing plan were usually run for four weeks with each oil. At the end of each run No. 1 piston was pulled, and the cylinder was carefully examined to determine the quality of lubrication. Notes were made of the extent to which the rings were stuck, gummy, dry, or well lubricated, and the location of gummy or carbonaceous deposits between rings or on piston skirts. All the carbon which adhered to the back of each ring was saved for weighing. Inasmuch as many fewer samples were available, the results of these weight determinations are not as clear cut as in the case of carbon in the exhaust passages, but they rate the oils similarly in most instances.

HEAVY-DUTY LUBRICATION

Table 2 shows the result of several tests made along the foregoing lines in a larger two-cycle Diesel engine where it has been found necessary to use an extra heavy grade of oil. In these tests additional information was secured by taking close-up pictures of pistons and cylinder walls. These formed a permanent record which amplified the notes and memory of the investigator for his final rating of the different oils. The more striking of these pictures are shown in Fig. 2.

The ratings in Table 2 based on piston charts[2] are entitled to considerable weight. These charts are illustrated in Fig. 3, and were found to be a convenient means of recording in logical fashion the position and size of carbon deposits, dry spots, gummy oil, etc., on pistons, rings, and cylinders for permanent reference in comparing oils. It was found that minimum reliance must be placed on memory in any careful comparison of lubricants.

The column headed "oil used" in Tables 1 and 2 is of interest as showing the variations which will occur for unknown reasons without readjustment of the lubricator.

The foregoing data are presented as illustrating the methods which were found necessary to select the best out of several oils which were under consideration for use in two-cycle engines. In many instances four-cycle engines do not give trouble from

[2] These were designed in cooperation with Messrs. W. G. Heltzel and J. B. Harshman, of the Sinclair Pipe Line Company.

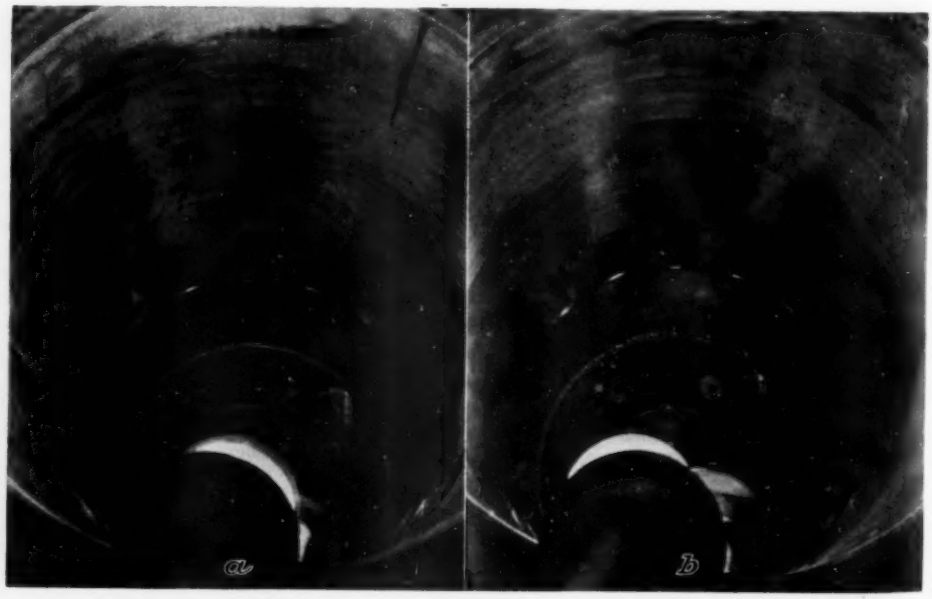


FIG. 2 TESTS TO SHOW THE CARBON-FORMING TENDENCIES OF OIL

(*a*, oil I; *b*, oil J. Compare with Table 2. The accumulations represent approximately 500 hours' operation in each case.)

TABLE 2 TESTS IN HEAVY DUTY TWO-CYCLE ENGINE

Oil	Oil used, qt.	Average load, %	Weight of carbon formed on: Rings 1–3[1]	Rings 4–7[1]	Lands 2–4[3]	Exhaust ports[2]	Order of merit shown by: Piston charts[4]	Exhaust-port pictures	Oil tests: Carbon residue	Viscosity at 210° F.
G.....	181	35.4	9.04	7.94	3.55	60.91	1	2	1.20	92
H.....	156	27.2	11.1	17.0	17.0	85.00	3	3	0.22	93
I.....	176	28.0	9.17	6.69	3.84	267.20	2	4	0.07	65
J.....	182	28.8	12.30	16.16	4.62	36.64	2	1	0.90	93

[1] On backs of rings only. Numbers show rings from which samples were taken.
[2] On flat perpendicular faces of ports.
[3] From spaces on piston face between rings 1 to 4.
[4] Estimates from detailed notes of piston and cylinder lubrication at time of inspections. Principal emphasis on oiliness of rings.
NOTE: All tests ran for close to 500 hours. Oil consumption and weights of carbon are corrected to a 500-hour basis. Engine was 750-hp., four cylinder, two-stroke cycle, port-scavenging, with piston-cooling. Weight and observations were from piston No. 1 only.

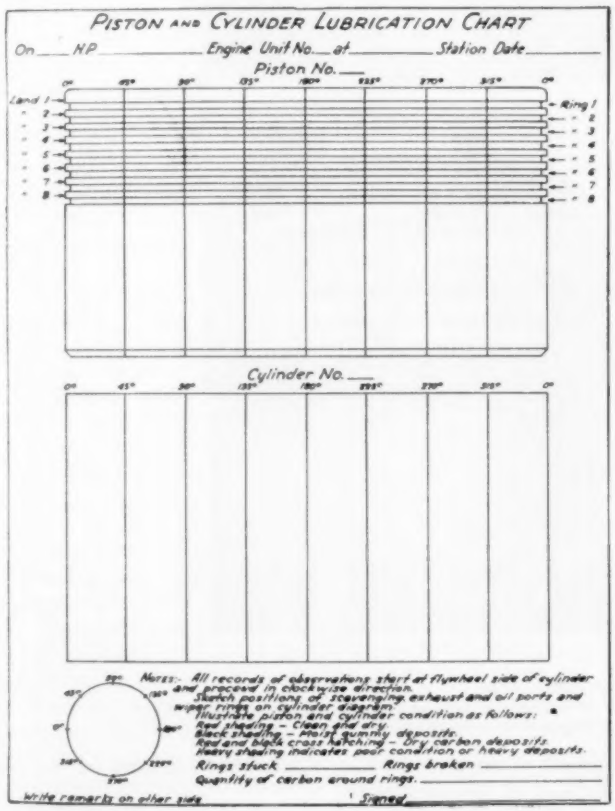


FIG. 3 CHART SHOWING RECORD OF PISTON AND CYLINDER LUBRICATION

deposits around the exhaust valves or passages, so that deposits on pistons and rings only need be considered.

WEAR OF FRICTION SURFACES

The feeling is prevalent that wear decreases as oil viscosity is increased within moderate limits.

This opinion seems reasonable, but is not adequately supported by available experimental data and should be the subject of further investigation. Excessive wear does not ordinarily show up in the bearings because the lower temperatures of such surfaces almost always permit even moderately light oils to lubricate properly. Oil films of suitable thickness are built up in the bearings, except of course under abnormal conditions. Cylinder and ring wear is, however, of considerable economic importance, and its measurement is being covered in detail in other papers. Such wear causes increased blow-by, with resultant loss of power, especially when the engine is on heavy load. The blow-by results in more severe heating and more rapid deterioration of the oil. Fig. 4 shows clearly the extensive gumming and carbonization taking place in the path of escaping hot gases at the ring gaps.

ROUNDNESS OF DIESEL CYLINDERS

The measurement of cylinder wear is not a test to be undertaken without careful consideration and preparation. The methods to be used to avoid errors in measurement and to avoid errors due to operating conditions are described elsewhere.

Diesel-engine cylinders differ in their degree of roundness. There is a pronounced corrugated effect in many cylinders, so that measurements within a few degrees of each other may differ by 0.001 in. or more. Table 3 shows marked differences in the degree of roundness of three Diesel-engine cylinders, expressed as the average difference in diameter from one position to the



FIG. 4 BLOW-BY AT RING GAPS

next when measuring the diameter every 15 deg. around the circumference. This emphasizes (*a*) that considerable blow-by and oil deterioration may be due to irregular cylinder walls and (*b*) that every possible precaution should be taken to standardize the point where cylinder diameters are measured in wear tests.

In addition to these variations as the micrometers are rotated around the cylinder, there are also more pronounced variations as the micrometers are lowered into the cylinder. Some Diesel cylinders wear to a regular taper from the top down, the greatest diameter being at the top. Others are barrel shaped, showing the greatest diameter from 4 to 8 in. from the top. In all cases there is very little wear at the bottom.

Fig. 5 shows pictures of the same pistons whose measurements are shown in Table 3. It will be noted that the amount of apparent blow-by is proportional to the extent to which the cylinders are irregular.

OIL CONSUMPTION

As in the case of motor oils, higher viscosities usually also result in lower oil consumption. In the case of engines which are in poor mechanical condition or overloaded, this saving may be quite important, but under ordinary conditions the difference may not be great.

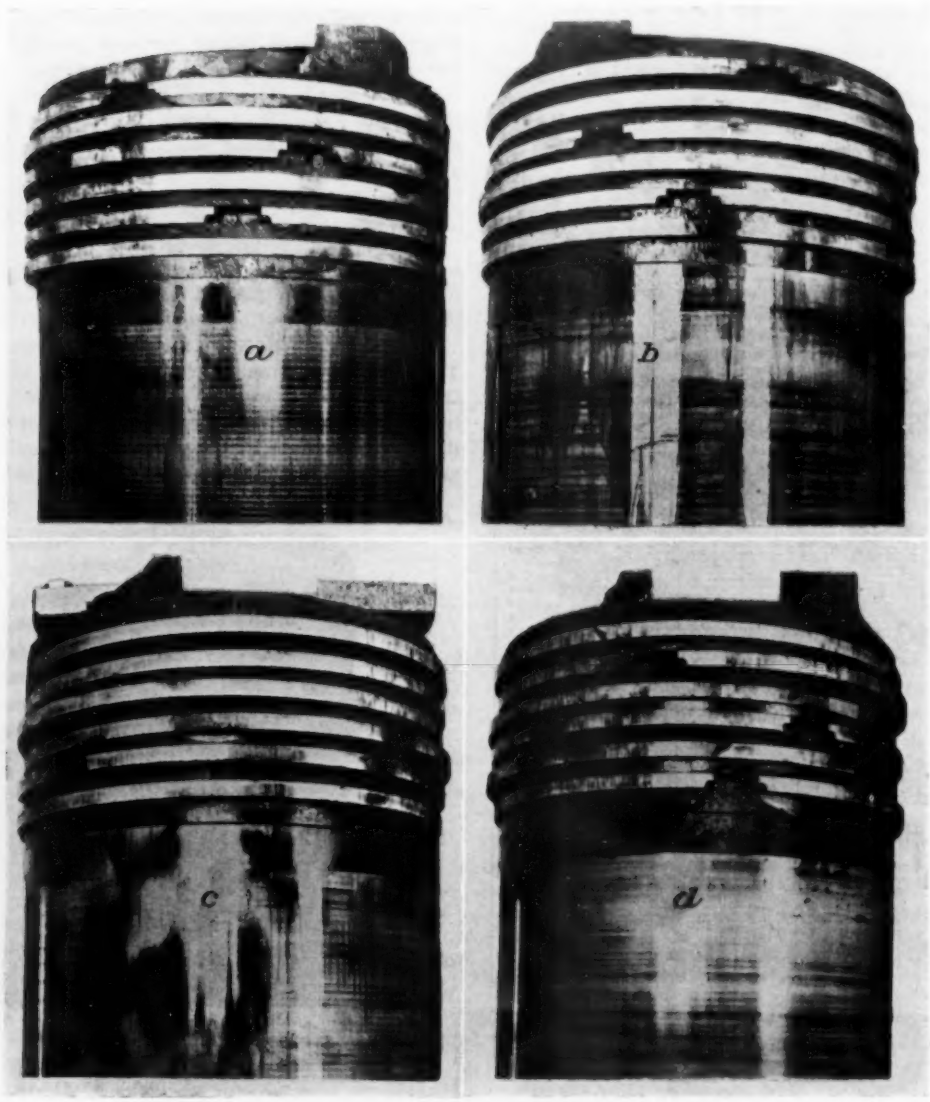


FIG. 5 BLOW-BY ON RING FACES

(*a*, engine 4, cylinder 4; *b* engine 3, cylinder 3; *c*, engine 3, cylinder 4, exhaust side; *d*, engine 3, cylinder 4, compressor side. Compare with cylinder measurements shown in Table 3.)

TABLE 3 DEVIATIONS FROM ROUNDNESS OF DIESEL-ENGINE CYLINDERS

Location	—Differences in diameter, in inches— Engine 4, Cylinder 4	Engine 3, Cylinder 3	Engine 3, Cylinder 4
Average 1 in. from top	0.0038	0.0042	0.0054
Average 2 in. from top	0.0033	0.0033	0.0059
Average 3 in. from top	0.0028	0.0032	0.0038
Average 4 in. from top	0.0028	0.0020	0.0037
Average 5 in. from top	0.0028	0.0017	0.0043
Average 6 in. from top	0.0028	0.0013	0.0018
Grand average	0.0030	0.0026	0.0042
Visible blow-by	Little	None	Much

Engines were 440-hp., two-cycle Nordbergs, running at 225 r.p.m., with valve-scavenging and port exhaust. Cylinders were 15 in. in diameter, and stroke was 20 in. Diameters were measured at 15-deg. intervals around the circumference. Differences in diameter from one point to the next are shown.

Compare the average deviations from roundness with piston pictures showing blow-by (Fig. No. 4).

Because of possible reduction in wear and, frequently, a reduction in oil consumption, there is a trend to the use of heavier oils for Diesel-cylinder lubrication. This has an analogy in the automotive field where the use of heavier oils is quite often carried to extremes because of smoother operation as well as reduced oil consumption.

PRACTICAL FIELD TESTS

Where Diesel oils are compared in service tests, too much emphasis cannot be placed on securing the same operating and mechanical condition for both oils. In this work it appeared that the following points should be considered:

Cylinder and Ring Wear. This affects the ring gap, which in turn will affect the amount of blow-by, with resulting piston fouling and loss of power.

Cylinder and Ring Conditions. When either are materially out of round or scored, the oil being used is obviously subjected to a disadvantage. Dark spots on outer faces of rings or on cylinder walls may indicate blow-by due to irregularly worn cylinders or rings.

Cooling-Jacket Scale. If this is allowed to accumulate, it will subject the oil to more severe conditions which will not be indicated from the other operating characteristics of the engine.

In extreme cases cracked cylinder heads may result from accumulations of scale. Conditions should be sufficiently uniform if in each test the engine has run the same length of time and with the same water supply since the last thorough cleaning.

Cooling-Water Inlet and Outlet Temperature. It would be desirable, although less important, to keep the inlet-water temperature and the flow in gallons the same as for all of the tests.

Load on the Engine. This should average the same for each test.

Timing and Fuel Distribution. With some engines this can be determined approximately from exhaust-gas temperature, which should be kept uniform between the different cylinders while in other engines it may be necessary to take indicator cards or to check the engine very carefully to insure that timing and load distribution remain uniform.

Exhaust-Gas Temperatures. In some types of Diesel engines where carbon accumulations in the exhaust passages are serious this is a most important consideration. In some cases, as already shown, comparatively small variations in average exhaust-gas temperature will cause quite large variations in the amount of carbon deposit in exhaust passages.

Procedure for Field Tests

Where it is possible to secure comparable operating conditions, as just outlined, either by testing the oils in similar engines running at the same time or in the same engine alternately, the various observations described in the preceding sections may be made.

In some cases it even may be necessary, because of the impossibility of following the tests closely, to eliminate certain parts and observations, but it is believed that by so doing the accuracy of the results is decreased. It was found that reliable comparisons were best secured when carbon samples were obtained quantitatively at regular intervals and weighed.

Frequently, helpful data may be secured by observing the presence and location of deposits or sludges which may drop into the crankcase from the cylinder or accumulate on the bottom or sides of the crankcase. The comparative amounts of these deposits should be estimated as closely as possible. Where possible, the sludges, if any, may be saved for later comparison of amount and composition.

Examination of the filter or centrifuge at regular intervals may show the relative amounts of sludge or deposits which accumulate from the same quantities of oil.

In most cases it will be very difficult to determine the relative fuel consumption for an engine when operating on two lubricating oils, since the error in making such fuel tests except under laboratory conditions is usually larger than the difference between the oils. Where good lubrication is being secured, there will be only a small difference in power consumption for oils differing considerably in viscosity.

Oil consumption is difficult to compare because of uncertainty as to just how low the feeds should be cut in each case and still secure sufficient lubrication. In any case the oil should be sufficient to maintain a light film of oil on pistons, cylinders, and rings, but anything beyond a reasonable surplus should be avoided.

All consumption records should be kept for the same time of operation in both cases, but unless the feed in each case has been carefully reduced to about the lowest practicable point little weight should be given to the results.

The comparison of Diesel lubricants is a matter of some difficulty, and usually facilities or the time are not available to properly make such tests. It would appear that the procedure cannot be simplified to the point where the respective merits of various oils can be determined accurately and easily.

Discussion

J. B. Harshman.[2] A description of the method used in determining the lubricating-oil film temperatures at the piston rings and a table showing operating temperatures would have been of considerable value to operators of Diesel engines in testing a lubricating oil to determine characteristics under different temperature conditions. It is believed that the amount of carbon formed in the cylinders of a Diesel engine depends largely on the condition of the cylinders. A badly worn cylinder, with gases blowing by the rings, will naturally form more carbon on any oil than if the cylinders were in first-class condition.

Under badly worn conditions, a heavier oil, which might possibly have a greater carbon content, will form a better seal and eliminate a large percentage of the blow-by, thus reducing the amount of oil burned on pistons and rings, and forming less carbon. For this same reason there is a possibility of reducing cylinder wear with a grade of heavier oil, by securing a better seal and reducing the blow-by and formation of carbon.

The author refers to two-cycle engines in which the scavenging air was compressed in the crankcase and with the tendency of the exhaust parts to clog up with carbon. It is believed that more or less trouble will be experienced with this type of engine, regardless of the nature of the oil used. This clogging of parts is due mainly to oil vapor and splash from the crankcase being carried through with the scavenging air into the cylinder. The amount of oil reaching the cylinders in this manner is usually beyond control of the operator.

The author states that an increase in exhaust-gas temperatures shows a decrease in the amount of carbon formation in the cylinder. It would be interesting to know the load that the engine referred to on test was carrying. This reduction of carbon formation with increase in exhaust-gas temperature is believed to be true up to a certain per cent of load due to better combustion. However, it is believed that on engines fully loaded any increase in exhaust-gas temperatures would be detrimental and would probably increase the amount of carbon formation due to burning a greater amount of the lubricating oil, as in the case of an overloaded engine.

The author also states that four-cycle engines do not give trouble from carbon deposits in the valve openings. The writer has found that four-cycle engines will give trouble from this source under various conditions, such as overload, poor quality of fuel, or excessive lubrication.

As to the author's statements in regard to checking up on the crankcase sludges, it is believed that no accurate data could be secured from these deposits as they might easily be caused by contamination or partial breakdown of the oil in the crankcase system and have no definite relation to the cylinder lubrication. It is believed that the author's experiments in the development of an oil with lower carbon content are a step in the right direction for the development of lubricating oils better suited to the various conditions of Diesel engine lubrication.

Author's Closure

The measurement of lubricating-oil film temperatures and the data obtained from several tests will be discussed in a paper which will appear in the near future. A knowledge of the heat condition which oils are subjected to in the various parts of an engine would of course be valuable, but so far as is known, data sufficiently comprehensive to warrant general conclusions are not as yet available.

Operating conditions and the condition of the engine will obviously exert a great influence on the amount of carbon which

[2] Sinclair Pipe Line Company, Tulsa, Okla.

will be formed with any oil, and as a matter of fact carbon formation is usually influenced more by such factors than by differences in the oils. Two-cycle engines were selected for test purposes because of their known tendency to form carbon faster than four-cycle engines, although, as Mr. Harshman points out, adverse conditions will cause excessive deposits even in the latter type.

The decrease in exhaust-carbon formation as the exhaust-gas temperatures increase was found throughout the range of exhaust-gas temperatures studied. It may well be that a reversal in trend would be found at higher temperatures, but these were not available in the test engine which was in regular plant service. The only reason in deriving curves showing this rélation was to permit tests of different oils run at slightly different average exhaust-gas temperatures to be converted back to a standard temperature for comparison.

The value of an examination of crankcase deposits in a study of cylinder lubrication will depend entirely on the type of Diesel engine. The test engine under consideration used the same oil for both crankcase and cylinder lubrication, the latter being supplied with used oil by means of a force-feed lubricator. The excess oil from cylinders drained out into the crankcase, and of course contributed materially to formation of deposits and crankcase-oil deterioration. In other instances where only new oil is used on the cylinders and where there is little opportunity for used cylinder oil to drain into the crankcase system, there would of course be little object in studying the deterioration of a crankcase oil.

PET-52-4

Economics of Pumping Oil at Low Friction Losses

By FRITZ KARGE,[1] LOS ANGELES, CALIF.

A study of California pipe lines and perusal of many articles in magazines of the oil industry indicate that most trunk-line systems are operated at pressures ranging around 750 lb. per sq. in. These pressures result from high friction losses in 8-in. pipe, which appears to be the predominantly favored size. This paper shows that the greater cost of larger pipe lines for pumping oil at lower friction losses will be returned in a comparatively short time by the saving in power cost. It also indicates the way toward a proper estimate of the power-operating costs for new lines.

Application of these principles to the redesign of existing pipe lines is not attempted since the wide variation in the arrangements and characteristics of such lines does not permit generalization. The principles apply nevertheless.

A number of California trunk pipe lines are too small in size. This is particularly evident in winter when the oil becomes cold and viscous. Many of these lines were laid before any definite knowledge had been developed concerning the friction losses in oil pipe lines. It is a more or less common occurrence that while holding the pressure at 800 lb. per sq. in. or higher, the pumps will move less and less oil until the line "freezes." It then becomes necessary to plug it out with light oil. Several means of improving this condition have been under consideration from time to time, such as steam-heating stations and booster stations at intermediate points between pump stations. Electric heaters were tested out on at least two lines. Looping of lines has also been suggested and resorted to more or less. None of these means, however, is entirely satisfactory and most of them cost more than can be justified.

The laying of larger lines to improve pumping conditions has also been thought of, having in view the use of standard line pipe. The cost of such heavy large lines has usually been considered prohibitive. Now changes in the art of making and joining pipe of lighter weight have brought the larger sized lines within economic reach.

WHEN designing a trunk pipe line for a new oil field recently the author made a study of the power costs for pumping at different rates through several sizes of pipe line. The results were so strongly in favor of the large-size low-friction pipe line that it was decided to carry this investigation further and to apply it to light-oil as well as heavy-oil pipe lines.

For the light-oil line a representative light Mid-Continent crude oil was chosen and a length of line of 30 miles, which in many cases is the distance between Mid-Continent pump stations. For the heavy oil a length of line of 15 miles was chosen, which is the customary distance between pumping stations handling such oil in California. The characteristics of the oils are given later. In both cases it was found that the low-friction pipe line would be very much cheaper in operation, and the saving in power would pay off the greater first cost in a few years. An additional saving would result for the larger lines from the wider spacing of pump stations possible because of the lower friction losses per mile. This is also brought out.

General Conditions

It is beyond the scope of this paper to discuss methods for determining the probable period of use and probable rate of pumping of a pipe line or pipe-line system. In designing any kind of a trunk pipe line, however, to run from field to refinery, from refinery to marketing center, or from field or refinery to ocean terminal, an assumption must be made as to the probable period of use of the line and as to the probable rate of pumping. The period would perhaps be shortest for lines carrying crude oil from a single oil field. Experience has shown that the life of an oil field is usually at least 15 years and for many fields very much longer. With this as a basis for the useful life of a pipe line, and in order to be entirely conservative, the operating costs used in this paper include fixed charges equal to 10 per cent per year of the first cost of the line, applied to a wide range of pumping rates.

Since some objection might be raised concerning the use of long, large-diameter lines, it seems desirable to point out that large, thin-walled pipes have been installed and successfully operated in numerous locations throughout the country for gas service, and in a few cases for oil service. Progress has been made in the knowledge of protecting pipes against corrosion, so that the use of light-weight pipe is no longer a matter of experiment.

This paper compares the two largest factors in the annual operating cost of pipe lines of $8^{5}/_{8}$ in., $10^{3}/_{4}$ in., $12^{3}/_{4}$ in., 14 in., 16 in., and 18 in., outside diameter, all of $^{1}/_{4}$ in. thickness. These factors are power cost and 10 per cent write-off. Steel pipe of 70,000 lb. per sq. in. tensile strength was chosen. The maximum allowable pressures were based on a safety factor of four. Mill shipment prices were assumed. The first costs include the cost of the pipe, right of way, ditching, welding, protecting, lowering, testing, and back-filling. The costs were carefully estimated and the figures were checked by a successful California pipe-line contractor. Assuming that only 25 per cent of the length of the lines requires protection because of adverse soil conditions, the cost of protecting such a portion of the lines was included and provides for a coat of priming paint, three coats of asphalt, and two layers of spirally wrapped pipe covering. The lines were assumed to be level, both for the first and power costs. Table 1 gives the main elements which were considered as making up the total cost per mile.

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[1] Engineer of Transportation, Union Oil Company of Calif. Mr. Karge was graduated in Civil Engineering from Throop College of Technology, now California Institute of Technology, Pasadena, Calif. He has been associated with his present concern since 1915. Until March, 1929, he was in charge of civil-engineering design and since then has supervised the design and construction of pipe lines, pump stations, tanks, reservoirs, and other facilities pertaining to the transportation of oil.

Presented at the National Petroleum Meeting, Tulsa, Okla., Oct. 6 to 8, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

TABLE 1 CONSTRUCTION COST PER MILE

Item	Outside diameter of pipe line—inches					
	8⅝	10¾	12¾	14	16	18
Cost of pipe	$4550.00	$5875.00	$7150.00	$7925.00	$9435.00	$11700.00
Hauling to job site (including stringing)	362.00	448.00	530.00	582.00	662.50	752.50
Ditching and backfilling	362.00	378.00	422.00	482.00	555.00	632.50
Aligning, welding, and lowering (including welding materials)	1025.00	1265.00	1505.00	1690.00	1900.00	2170.00
Inspecting and testing	159.50	193.00	238.00	280.00	331.00	392.00
Protective coating (25 per cent)	356.00	453.00	513.00	585.00	655.00	750.00
Surveying and superintendence	316.00	343.50	370.50	395.00	422.00	452.00
Miscellaneous (valves, fittings, bends, street crossings, railroad crossings, etc.)	357.50	407.50	489.00	553.50	624.50	693.50
Right of way and franchises	725.00	725.00	725.00	725.00	725.00	725.00
Contingencies	422.00	512.00	632.50	682.50	790.00	932.50
Total cost per mile	$8635.00	$10,600.00	$12,575.00	$13,900.00	$16,100.00	$19,200.00

Electric power was assumed because of the greater simplicity of comparison and the fact that an increasing number of pump stations use electric power for their prime movers. A rate of 1½ cents per kw-hr. was taken as being an average cost for electric power for pumping service. For the light-oil line no heating was considered, whereas the heavy oil was assumed to be heated to 150 deg. fahr. The means and the cost of heating are not discussed in view of the fact that steam pumps will usually be chosen where the oil has to be heated and exhaust steam will then be available for heating. If the cost of fuel oil and water are properly figured, the cost of steam power will ordinarily be found to be in excess of the cost of electric power. Using the cheaper electric power therefore for the heavy-oil line places the principle expressed herein in a less favorable light. It is felt that this is a simplification on the conservative side.

Power derived from Diesel engines is usually found to be cheaper than electric power. If the cost of power alone were considered for such installations the lower Diesel-engine power cost would result in a less favorable demonstration of the principle of this discussion. However, it is certain that Diesel engines for high-pressure pumps will cost considerably more than those for low-pressure pumps. This increased first cost for the Diesel engine for high-pressure pumps will partially or perhaps entirely offset the excess cost of the larger line. The great variety of Diesel engines available and the varying costs of their generated power made it inadvisable to consider them in detail.

An overall efficiency of 60 per cent was assumed for motor and pump. This value represents average performance of centrifugal pumps. The assumption of higher efficiency for the low-pressure pumps than for the high-pressure pumps would have been justified, and the resulting power costs would have favored the contention of this paper.

The light oil chosen is a typical Mid-Continent crude oil of the following characteristics:

Temp., deg. fahr.	Absolute (poises) viscosity	Specific gravity	Kinematic viscosity (poises)
40	0.1903	0.8443	0.226
60	0.1303	0.8363	0.156
80	0.0845	0.8283	0.102

The friction calculations were made with the assumption that the light oil would be at 60 deg. fahr. temperature.

For the heavy oil a California crude was used, having an A.P.I. gravity of 13.8. Complete characteristics for this oil are shown in Fig. 4. The heavy oil was assumed to be pumped at 150 deg. fahr. and to cool in the line because of the ground temperature of 60 deg. fahr.

The friction losses in the pipe lines were calculated by the formulas for flow of fluids through pipes as given in Walker, Lewis, and McAdams' "Principles of Chemical Engineering," 1927 edition. The values so computed were compared with those obtained by using the formulas given by R. S. Danforth, of the Kinney Manufacturing Company, in his booklet, "Friction Pressure Loss in Oil Pipe Lines." The friction-loss curves resulting from the two methods are so nearly in agreement that the difference in the ultimate result is negligible. The temperature losses in the heavy-oil line were calculated, using the charts in "Oil Flow Viscosity and Heat Transfer," published by Mr. Danforth.

Again for the sake of conservatism, the cost of pump-station installations for high and low pressures was not considered. The higher cost of high-pressure pumps and motors would partially offset the higher cost of the larger pipe lines for which lower-pressure pumps and smaller motors would be in order. It requires no proof that the low-pressure pumping installations would have a longer life and require less maintenance than high-pressure installations. These features add strength to the conclusions reached. It can further be assumed that low-pressure pipe lines will also require less maintenance.

TABLE 2 FARTHEST POSSIBLE SPACING OF PUMP STATIONS

From Fig. 1					From Fig. 3	From Fig. 1		
Throughput at max. press. small line, bbl. per hr.	Small line 30-mi. long		Next larger line		Years pay-off period	Max. press. permissible larger line, lb. per sq. in.	Longest dist. for larger line at max. press.	
	Size, in.	Lb. per sq. in.	Size, in.	Lb. per sq. in.			Size, in.	Distance, miles
1200	8	1100	10	360	1.2	850	10	71.0
2000	10	850	12	360	1.2	720	12	60.0
3000	12	720	14	445	0.7	650	14	44.0
3750	14	650	16	350	1.0	575	16	49.0
5050	16	575	18	315	1.2	500	18	47.5

The advantage of pumping through large lines at low-friction losses is demonstrated in the charts given herein.

Light Oil Lines

Fig. 1 shows the pressures in lb. per sq. in. required to pump light Mid-Continent crude at 60 deg. fahr. through the different-sized pipe lines, all 30 miles long, at rates from 200 to 6600 bbl. per hour. The dotted line across the top of the curves indicates the maximum pressures which the different pipes can stand with a safety factor of four. The pressures necessary for handling 1000 bbl. per hour, for instance, would be as follows:

Size line, in.	Lb. per mile	Lb. for 30-mile line
8	26.70	800
10	8.67	260
12	3.74	112
14	2.92	70
16	1.23	37
18	0.67	20

The pressure-capacity limit line shows that the maximum rates of pumping vary from 1200 bbl. per hour in the 8-in. line to 6600 in the 18-in. line. For lines shorter or longer than 30 miles the pressures will be proportional, the friction loss per mile remaining the same.

Fig. 2 shows the operating costs in dollars per year per mile for rates of pumping from 400 to 4500 bbl. per hour. The costs include the electric power cost and 10 per cent of the cost of first installation, all reduced to cost per mile. For a 30-mile line,

these figures should be multiplied by 30; for shorter or longer lines by their respective lengths.

It will be noted that at the lower pumping rates the curve for each size pipe line crosses the curves of all smaller-size pipe lines. This indicates that at these lower rates the operating costs are less for small than for large lines. This condition, however, applies only for a short range. The 8-in. pipe, for instance, is cheaper to operate than the 10-in. line only when the rate of pumping is below 500 bbl. per hour. At 1000 bbl. per hour the 8-in. line is more expensive than any of the others, costing about $2600 per mile per year. The cost of operating the other lines at the same capacity is as follows:

Size line, in.	Cost per year per mile, dollars
12	1500
14	1550
10	1630
16	1770
18	1990

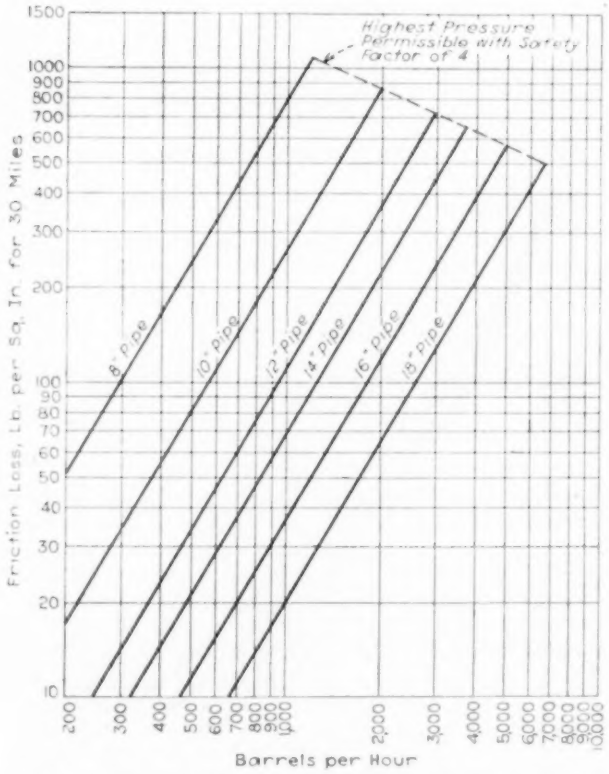


Fig. 1 Pressures Needed to Pump Light Oil Through Pipe Lines of Different Sizes

At 2100 bbl. per hour the cost of operating the 16-in. and 18-in. lines are the same, amounting to $2250 per year per mile. All other lines are more expensive. The upper points on the curves for the 8-, 10-, 12-, and 14-in. lines indicate the maximum rate at which pumping through these lines is possible as determined by the strength of the pipe.

It can also be seen in Fig. 2 that the economic pumping pressures are considerably below the maximum pressures that the pipes can stand, i.e., this is the case in large low-friction lines. As a result such lines not only operate more safely, but will have a large excess capacity available for peak loads due to flush production or emergency movements of oil. To handle such cases it will only be necessary to use the stand-by pumps or to get larger ones. If a system is ordinarily operated at high pressure, i.e., near the pressure-capacity limit of the pipe, peak loads cannot be accommodated. Winter conditions, furthermore, will not affect a large line as adversely as a small one.

Fig. 3 shows the years required for the operating savings in any size line to pay off the difference in first cost between it and the next smaller size line when pumping at different rates. When pumping at 1000 bbl. an hour for instance, the 10-in. line will pay off the difference between its first cost and the first cost of the 8-in. line in two years. At 2000 bbl. per hour, the 12-in. line will return its greater cost over the 10-in. line in about 7 months, and the 14-in. line will return its greater cost over the 12-in. line in about a year and seven months. If a period of 10 years is taken in which to effect a saving equal to the difference in first cost, it is readily seen that this can be accomplished with relatively low pumping rates.

At this point a few remarks relative to the economic spacing of pump stations seem in order. Table 2 gives the pay-off periods required for the savings in operating costs in any size

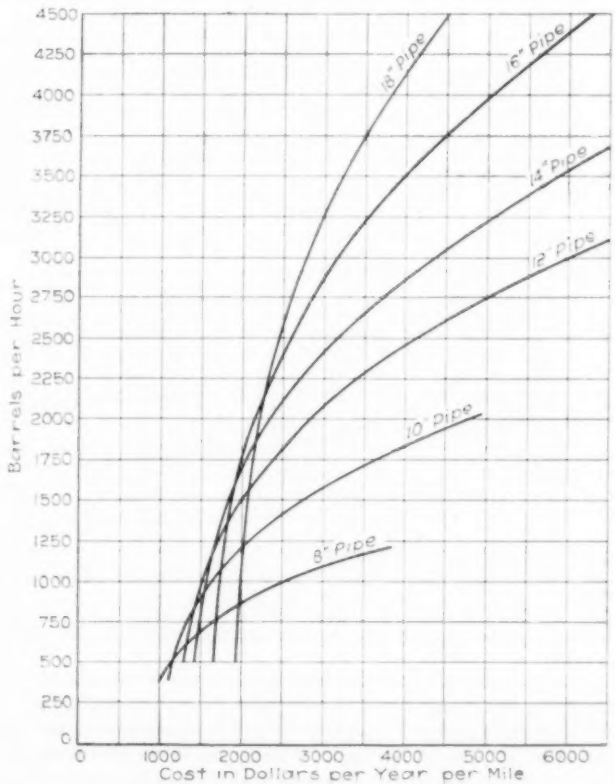


Fig. 2 Operating Costs for Different Rates of Pumping

line to pay off the difference in first cost between it and the next smaller size line when pumping through 30 miles of line at the rate producing in the smaller line the highest pressure consistent with a safety factor of four. The highest permissible pressures are also tabulated. The last column gives the distance through which the oil can be moved through the larger of any two lines under consideration, if the pressure were brought to this highest value, and if the rate of pumping were maintained that produces the highest pressure in the smaller line. This means that the pump stations in the larger of any two lines could be placed very much farther apart than in the smaller line of 30 miles length. In practice, pumping at the highest allowable safe working pressure may not be admissible. Nevertheless, an appreciably wider spacing of pump stations would be entirely

in order, and would result in an additional saving of considerable magnitude.

Heavy-Oil Lines

The consideration of the heavy-oil line is based throughout on a pumping rate of 1000 bbl. per hour. This rate was chosen since it is one aspired to, but seldom reached, in similar lines in California. It seemed inadvisable to develop these diagrams for different rates of pumping because of the many kinds of heavy oils of different characteristics and the varying limits of heating and cooling encountered in practice. The one example offered will demonstrate the principle.

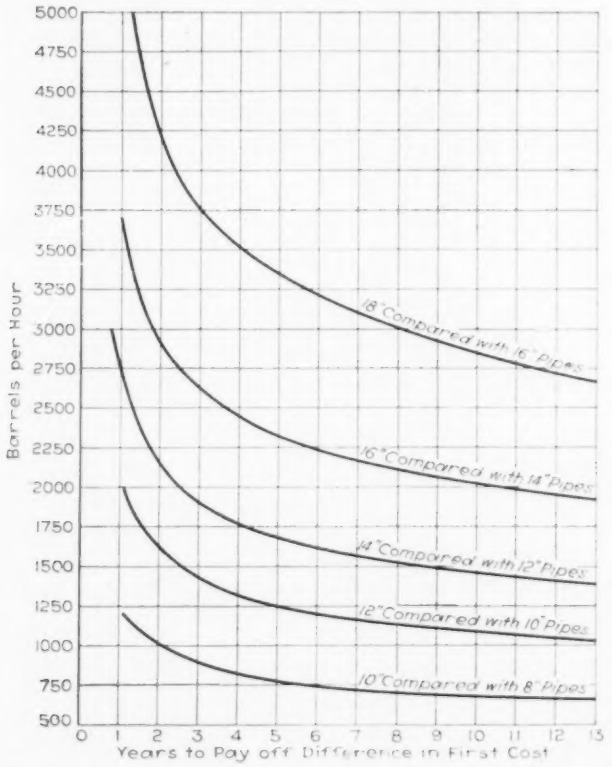


Fig. 3 Time Needed for Savings to Pay Off Difference in First Cost Between Any Line and the Next Smaller Size Line

The characteristics of the heavy California crude oil used to illustrate the design for a 15-mile pipe line are given in Fig. 4. To find the kinematic viscosity at any temperature of the oil, the chart is followed horizontally along the desired temperature to an intersection with the curve, and thence vertically to an intersection with the specific gravity corrected to the temperature. From this point a position parallel to the diagonal guide lines is followed to the upper scale where the kinematic viscosity may be read.

Temperature gradients in the different size lines when pumping 1000 bbl. per hour, initial temperature of 150 deg., ground temperature 60 deg. fahr. are shown in Fig. 5. The line was divided into one-mile sections, and the temperature drop for each section computed from Danforth's heat-loss charts.

It can be seen that the larger the line the better the oil retains its heat for the same rate of flow. This has been demonstrated in tests and in practice. In consequence, in the larger line the oil is pumped at a lower average viscosity, and its higher temperature will keep down solidification of wax, if this substance should be present in the oil.

The friction loss per mile of line when pumping the heavy oil at a rate of 1000 bbl. per hour is shown graphically in Fig. 6. The friction losses are given for the viscosities corresponding to the temperatures within the limits of the temperature gradients shown in Fig. 5.

TABLE 3 PAY-OFF PERIODS FOR THE HEAVY-OIL LINE FIFTEEN MILES LONG

Pipe diameter,[1] in.	Yearly power cost, dollars	Diff. yearly power cost, dollars	Diff. in first cost, dollars	Years req. to pay off first cost difference
12	49,200			
		6974	19,880	2.8
14	42,226			
		5586	33,000	5.9
16	36,640			
		1304	46,500	35.6
18	35,336			

[1] The 8-in. and 10-in. lines are not listed since they cannot handle the oil for 15 miles at 1000 bbl. per hour rate.

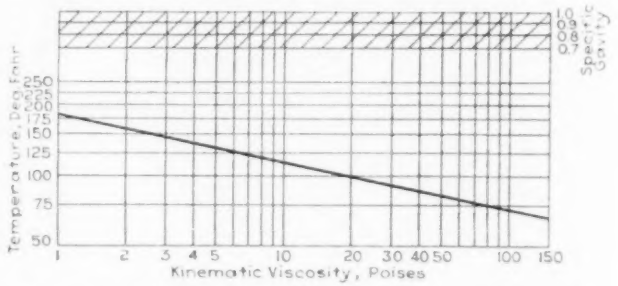


Fig. 4 Characteristics of Heavy California Crude Oil

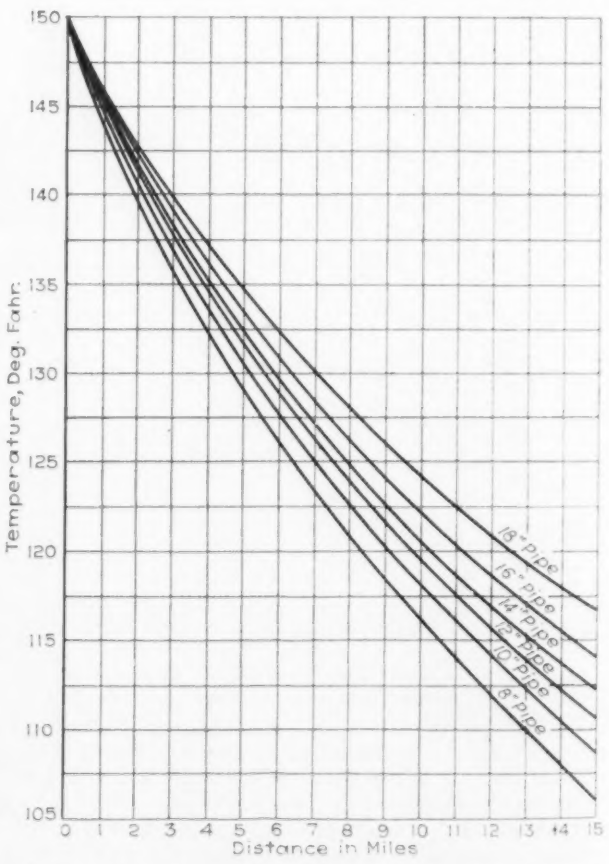


Fig. 5 Temperature Gradients in Different Size Lines

Fig. 7 shows the operating costs per year for pumping 1000 bbl. of heavy oil per hour through lines of lengths from 1 to 15 miles. The procedure used in drawing up this form of chart is as follows:

From Fig. 5 the mean temperature is obtained for each successive mile of the pipe line. From Fig. 4 the kinematic viscosities are determined of the oil for each of these mile sections. Next, from Fig. 6 the friction loss is found for each of the miles and these are added. This gives the necessary pumping pressure. Using the power figure of $1^1/_2$ cents per kw-hr. with an overall

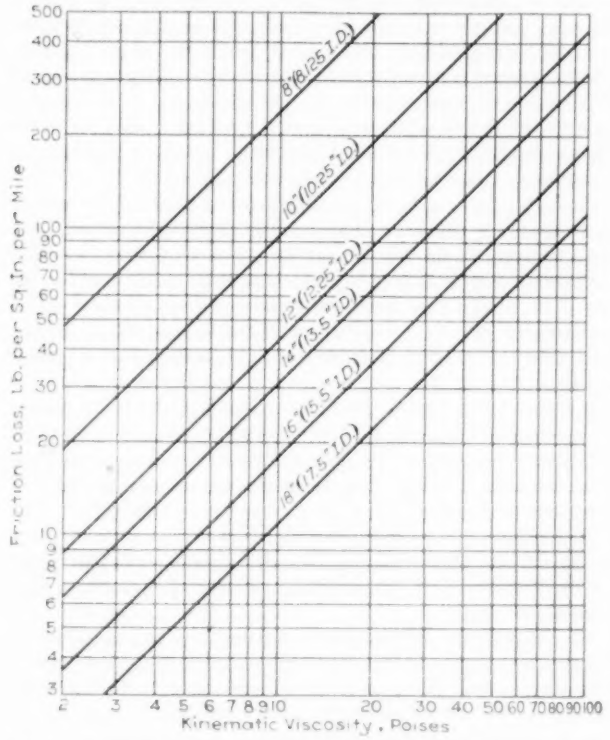


FIG. 6 FRICTION LOSS PER MILE OF LINE WHEN PUMPING HEAVY OIL

efficiency of 60 per cent, the yearly power cost for this pumping pressure may be arrived at. If this power cost is then combined with the fixed charges, which are assumed to be 10 per cent per year of the installation cost, the values shown in Fig. 7 result.

The computations show that the 8-in. line can handle this quantity of 1000 bbl. per hour only through a distance of a little less than 10 miles, and the 10-in. line through 14 miles, when pumping at the highest pressure consistent with a safety factor of four. These limits are beyond the range of the chart.

CONCLUSIONS

From the foregoing analysis it can be seen that the use of large pipe lines at low-friction losses for pumping oil is the most economical arrangement. The use of the figures to solve specific problems is proper only when the oil characteristics are the same. It is, however, possible to study the economics of any proposed pipe line by applying the procedure as set forth in this discussion. Since the spacing of booster stations, the selection of pumping, heating, and other equipment will all be influenced by the size of the pipe line, the necessity for a comprehensive analysis of all factors pertinent to any project is evident.

It seems that many of the old oil trunk lines operate with uneconomically high friction losses. From the foregoing discussion it follows that the oil industry would lessen future oil-pumping costs by laying low-friction lines in all new trunk-line installations. It is probable that in many cases, particularly of lines that are expected to be operated for years to come, appreciable savings would result from a careful redesign and reconstruction with

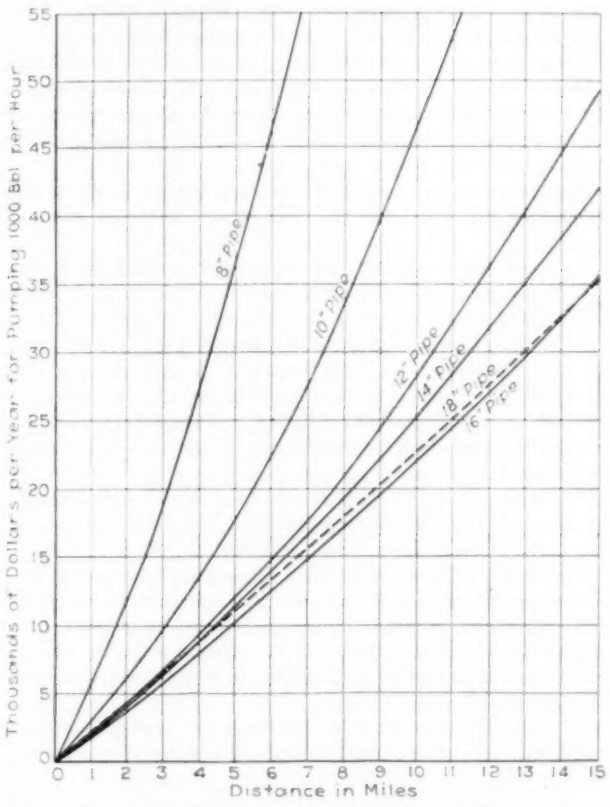


FIG. 7 OPERATING COSTS FOR PUMPING HEAVY OIL THROUGH LINES OF VARIOUS LENGTHS

larger, low-friction loss lines. Some of the large pipe-line companies are now in a position analogous to that of the railroads, in that increased profits must be principally derived from operating economics. These are often possible only after the courageous and well-planned expenditure of money to improve operating conditions.

The author wishes to acknowledge the assistance of L. V. Horne, Mechanical Engineer, Union Oil Company of Calif., and L. M. Miller, Civil Engineer, Union Oil Company of Calif., in the preparation of this paper.

Discussion

R. S. DANFORTH.[2] There has been a tendency among many oil companies owing to the rapid changes in that industry to feel that any expenditure must be repaid in one or two years to justify its installation. On this basis many installations are omitted that would pay good returns on the investment, and the author seems to have called desirable attention to one of these possibilities.

In the paper a number of items favoring the low-pressure line have been intentionally disregarded, but opposing that, the fixed charge of 10 per cent per year seems low if interest on the investment is to be included. Possibly the author intends the saving shown to balance interest on the increased investment.

For temperature drops the charts in "Oil Flow Viscosity and Heat Transfer" were used. These charts were based on accurate data of 8-in. pipe lines of the General Petroleum Company, using recording thermometers for the ground temperatures.

Few test data were available at that time on other sized lines

[2] Pacific Coast Manager, Kinney Manufacturing Company, San Francisco, Calif. Mem. A.S.M.E.

where the ground temperature was accurately known. The effect of variation of size of pipe was deduced by dimensional analysis, and values were suggested pending the availability of more accurate data with known ground temperatures. It would be interesting to know if any tests of other sizes are available at the present time with the ground temperatures accurately known.

The author is to be congratulated on the study given this important subject and the thorough way it has been handled.

W. H. STUEVE.[3] This paper proves in conclusive form that the transportation of crude oil could be made much cheaper by installing larger-sized pipe to reduce friction losses, instead of operating at maximum pressures allowable for a given pipe, but to operate them at lower pressures through a larger pipe line for a like volume of oil pumped, thereby reducing the power requirement cost of station operation, which saving would tend to repay the operating company for increased cost of the larger line required.

It is noted, however, that the curves shown in Fig. 3 are developed by using an electric power cost of 1.5 cents per kw-hr. and "overall" centrifugal pump efficiency of 60 per cent. It is the experience of most pipe-line engineers that a net rate of 1.5 cents per kw-hr. for 100 per cent load factor and for demands of 200 to 500 kw. will not be competitive with oil engines. The curves shown in Fig. 3 are all based on 100 per cent capacity or pumping rates maintained for 8760 hours per year, and hence 100 per cent electrical load factor.

By using the following assumptions to develop an electric rate which will be competitive with oil engines—

(*a*) Oil-engine pump station will cost $3\frac{1}{2}$ times that of centrifugal station, including standby unit of $\frac{1}{2}$ total capacity
(*b*) 15-year life of equipment, 12 per cent total fixed charges
(*c*) Plunger-pump efficiency, 90 per cent
(*d*) Centrifugal-pump efficiency, 70 per cent
(*e*) Motor efficiency, 92 per cent
(*f*) Fuel 0.5 lb. per b.hp-hr. at $2 per bbl.
(*g*) Oil-engine station labor cost 2 times that of electric centrifugal
(*h*) Oil-engine station lubrication 9 times that of electric centrifugal.

From which it is found that an electric rate of approximately the following description will enable electric motors to compete with oil engines as prime movers;

Load factor	Permissible power cost, cents per kw-hr.
100	1.00
90	1.05
75	1.17
50	1.45

All power companies supplying energy for pipe-line pumping in the Mid-Continent oil field have rates of this approximate character.

Referring to curves on Fig. 3, it is noted that when pumping at rate of 1000 bbl. per hour, if 10-in. pipe had been installed instead of 8-in. pipe, the lower power requirements of the 10-in. station would permit it to pay back in two years the difference in installed cost of 10-in. pipe, as against using 8-in. pipe. By using an electric rate of 1 cent per kw-hr. at 100 per cent load factor, it is found that this pay-off period is extended to 3.3 years.

Also, the author should take into account the fact that centrifugal-pump efficiencies will be considerably better when pumping 24,000 bbl. per day in the 10-in. line at 260 lb., instead of a like volume at 800 lb. in the case of the 8-in. line. If this is taken into account, and an overall efficiency of 70 per cent were used, the pay-off period would be three years.

Laying aside the aforementioned difference in pump efficiencies, and assuming that a figure of 60 per cent overall is correct for both 8- and 10-in. volumes and pressures, and again use a value of 1 cent per kw-hr. when pumping at the rate 750 bbl. per hour, it is found that the pay-off period in the case of 8-in. line, as against a 10-in. line, is extended to 11.5 years instead of 5.5 years, as shown on the curves of Fig. 3. This is a long time to project estimated pumping conditions, and therefore the savings effected by using the larger 10-in. pipe may not make much impression on the executives.

As stated previously, all conditions of the developed economic analysis in this paper are based on pumping at the same hourly rates throughout the year for a great number of years to follow.

Experience with known capacities in main trunk lines for the last 4 or 5 years has shown that 100 per cent capacity is not maintained. Trunk lines of three of the largest pipe line companies delivering oil to Chicago and St. Louis have been operating on a 70 to 75 per cent capacity for the last several months and expect to operate at this rate for a period of 6 to 12 months in the future. Therefore some consideration should be given to "capacity factor" over a period of time in making predictions or developing curves to indicate when certain capital expenditures could be recovered if larger lines are installed.

It is suggested that an interesting set of curves, such as shown in Fig. 3, could be developed by using an annual capacity factor of 75 per cent or some such figure as would usually be met with in practice.

The hypothesis in this case would be that pumps would be installed to handle 1000 bbl. per hour and with 60 per cent overall efficiency at that point, but would operate only for 18 hours per day at 800 lb. in case of 8-in. pipe line; therefore, an electrical monthly load factor of 75 per cent is achieved to deliver 18,000 bbl. per 24 hours or 75 per cent capacity factor.

The permissible electric power rate would be 1.17 cents per kw-hr. at 75 per cent load factor. If this condition of hypothesis is maintained for a period of one year or longer, the savings amount to $15,400 per year by using 10-in. pipe as against using the smaller 8-in. pipe, and therefore the increased investment of the larger pipe would be repaid in 3.9 years.

Likewise at 90 per cent capacity factor or electric load factor, when pumping at maximum rate of 1000 bbl. per hour for $22\frac{1}{2}$ hours per day, and using an electric rate of 1.05 cents per kw-hr., the pay-off period is reduced to 3.5 years, for an average delivery of 22,500 bbl. per day.

These figures will hold true only for centrifugal pumps, and a separate study for reciprocating pumps would be necessary, since the most economic method or rate of pumping for 75 per cent capacity factor would be to operate two reciprocating pump units each of 12,000 bbl. capacity per day for 12 hours and one unit for the remaining 12 hours rather than both units for 18 hours, the energy consumption being in this ratio as 77 is to 100.

Another factor not taken into account is the fact that the pressure-volume curves shown in Fig. 1 are apparently based on crude of 80 Universal Saybolt seconds viscosity, and consequent results shown in Fig. 3 pay-off periods, for average Mid-Continent crude.

The annual average temperature for crude flowing in lines in Oklahoma and Texas is approximately 68 deg. fahr. for lines buried 2 ft.

The average viscosity of Mid-Continent crudes at 68 deg. fahr. and 35 deg. A.P.I. gravity will approximate 70 Universal

[3] Oklahoma Gas and Electric Company, Oklahoma City, Okla.

Saybolt seconds or 0.145 kinematic viscosity (poises), and in most cases 50 to 60 Universal Saybolt seconds.

When pumping 1000 bbl. per hour through 30 miles of 8-in. pipe line, the initial pressure required is 720 lb. for 70 Universal Saybolt seconds crude. Likewise when pumping the same amount through a 10-in. line the initial pressure is 240 lb.

The power requirements from the foregoing data, plus fixed costs on the pipe line, again extend the time of recovery of capital expenditure for the difference in first cost between an 8-in. and a 10-in. line from 2 years, shown in Fig. 3, to 2.3 years. Likewise, when pumping 750 bbl. per hour through 30 miles of 8-in. pipe line, the initial pressure is 430 lb. for 70 Universal Saybolt seconds crude oil, and 150 lb. initial pressure when pumping a like amount through a 10-in. line. In this case the difference in capital expenditure for the larger 10-in. line as against using 8-in. pipe will be recovered in 7.3 years, instead of the 5.5 years indicated in Fig. 3, using an electric energy rate of 1.5 cents per kw-hr. and 60 per cent overall centrifugal-pump efficiency in both cases.

As a whole the theories developed in the paper are well proved, but the writer believes that from a practical viewpoint the curves as developed in Fig. 3 should be extended, based on conditions found in actual practice in the field with regard for capacity-load factors and temperate-viscosity changes. Therefore the conclusions reached would carry more weight with practical pipe-line executives, engineers, and designers.

Author's Closure

For the sake of simplicity the figures in the paper were developed for a section of pipe line 30 miles long and only for one set of conditions, which were believed to be average conditions. The necessity for a comprehensive analysis of the factors pertinent to any project was emphasized, since the spacing of pump stations and the selection of pumping, heating, and other equipment would all be influenced by the size of the pipe line. The paper suggests that figures similar to those in the paper, but constructed on the basis of all conditions pertinent to the project in hand, would show that the low-friction-loss line of larger diameter will be the more economical line to build.

Mr. Stueve in his discussion points out the effect on the figures of lower power rates, higher overall efficiency of pumping equipment, and of lower load factor resulting in the extension of the pay-off periods, without, however, vitiating the principles brought out in the paper. The paper itself refers to the lower power rates attained with oil engines and suggests that the saving possible with larger lines by the wider spacing of pumping stations will partially or wholly offset the higher cost of larger lines.

Even with power rates as low as suggested by Mr. Stueve, the larger lines will prove therefore more economical.

Again, for the sake of simplicity the paper made no allowance for this saving in pumping stations. The wide variation in cost of pump stations would have complicated the figures. Sample calculations were made, however, with power rates as low as 1 cent per kw-hr., proving the contentions of the paper.

The paper also states that for any pipe-line project an assumption must be made of the probable period of use of the line and of the probable rate of pumping. Such an assumption must include the consideration of the load factor. Trunk lines are built ordinarily with the expectation of an improving load factor.

It is evident that the trend in pipe-line installation is toward larger lines. The saving in power costs possible through the use of larger lines has of course been always known. The installation of larger lines has become practicable and economically advantageous through the very marked improvements in the art of making and joining large-size thinner-walled pipe.

PET-52-5

Temperature Observations for One Year on Streams of Petroleum Flowing in Mid-Continent Oil Pipe Lines

By BERT MARTIN[1] and WILLIAM G. HELTZEL,[2] TULSA, OKLA.

The designer of an oil-pipe-line system could obtain valuable data on the contraction of the lines if he knew more about the temperature variations of the oil flowing through them. In the transportation of oil over long distances through pipe lines, a change in the temperature of the oil is likely to occur, thus affecting the volume. It is valuable to be able to predict the amount of change in volume for temperature changes over long distances. An important factor is the viscosity of the petroleum, for temperature variations in the oil stream cause the viscosity to vary. The paper shows how these results may be obtained, and gives charts as an indication of the temperature conditions of the oil flowing through the oil-pipe-line systems of the Mid-Continent.

KNOWLEDGE of the underground temperature of oil pipe lines is important, both in the design and operation of an oil-pipe-line system of any length.

Oil pipe lines are laid without expansion joints, and the contraction in the pipe line is provided for by crowding the pipe line into the ditch. It is a rule-of-thumb method in pipe-line practice for providing sufficient "slack" in the line to take care of the contraction. The past history of pipe-line operation is filled with repeated failures caused by the oil pipe lines pulling apart at the joints, especially for the screwed-coupling line, during cold weather or at a time when sudden changes of temperature occur in the ground. It is believed that with information as to temperature variations in these lines, more consideration can be given to the contraction of the lines in designing a pipe-line system.

In the transportation of petroleum over long distances through pipe lines a change in the temperature of the oil is likely to occur, resulting in either a shrinkage or an expansion in the volume of petroleum. It is worth-while information to be able to predict the amount of change in the volume of oil for temperature changes over long distances.

In the design of an oil-pipe-line system, one of the most important factors in the hydraulic calculations is the viscosity of the petroleum, and consequently something must be known beforehand as to the temperature variations of the oil stream in the pipe line; for the viscosity of the petroleum varies widely with the temperature. In order to compute pipe-line pressures, capacities, and horsepower required for a new pipe line, the average temperature of the oil stream should be known, since both the density and the viscosity of the oil are affected by temperature.

It has been pointed out that in the design of oil pipe lines, information as to temperature variations is important in order to provide sufficient "slack" for the contraction in the lines. But since no scientific way of providing for the sufficient amount of slack is used in the construction of oil pipe lines, failures will occur from time to time. Some knowledge as to when minimum temperatures are reached and when the greatest temperature variations occur will aid the men responsible for operation in watching for the failures due to the lines contracting. No trouble, except for leaking couplings, is experienced from the expansion of buried lines. For this reason it is the policy of some pipe-line companies to lay their lines, if possible, during the months of the year when fairly low temperatures prevail.

Purpose

It is the purpose of this paper to present such temperature data for oil pipe lines as might prove helpful both in the design and operation of oil-pipe-line systems in the Mid-Continent area. The average daily temperatures, covering a period of one year, for the oil streams flowing through pipe lines across the various states of the Mid-Continent are presented herewith. It is hoped that these data on average temperatures and the fluctuations in the temperature will prove helpful in the design and operation of oil-pipe-line systems.

Method of Obtaining Temperatures

The temperatures of the oil streams were obtained at four oil-delivery points on a pipe-line system; one near East Chicago, Ind., one in Missouri, one in Kansas, and another at Houston, Tex. A recording thermometer with two bulbs was used for obtaining the oil and the atmospheric temperatures. The one bulb was inserted as a tight fit in a separable steel sock, directly in the stream of the petroleum. The bulb was properly insulated from atmospheric temperature influences. The other bulb was exposed to the atmosphere and protected from unnatural atmospheric temperature variations. Each thermometer was calibrated against a certified mercury thermometer; and at the end of each month, and in some cases every two weeks, the temperature shown on the recording chart was checked with an accurate mercury thermometer by obtaining the temperature of a gallon sample oil drawn from the line.

Once a week the temperature charts were mailed to a central point, and the average temperatures were obtained with a planimeter. Any discrepancies in the recorded temperatures were watched for closely, and any variation from the expected result was checked immediately at the place where the temperature was measured.

Results

These temperature observations are shown in Figs. 1, 2, 3, and 4.

Fig. 1 shows the average temperatures of the continuous stream of oil-received at an oil-delivery point near East Chicago, Ind. These results should be typical of an oil stream flowing in a northeasterly direction across the northern part of Illinois, and likewise across Missouri.

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[1] Tank Table Engineer, Sinclair Pipe Line Co.

[2] Mechanical Engineer, Sinclair Pipe Line Co. Assoc-Mem. A.S.M.E.

Presented at the National Petroleum Meeting, Tulsa, Okla., October 6 to 8, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

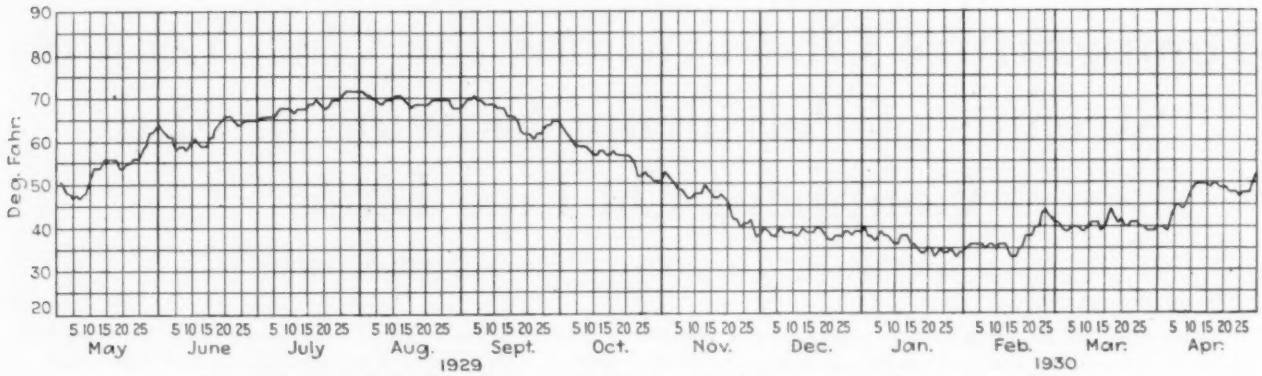


FIG. 1 AVERAGE DAILY TEMPERATURE OF PIPE-LINE OIL STREAM IN THE STATE OF ILLINOIS

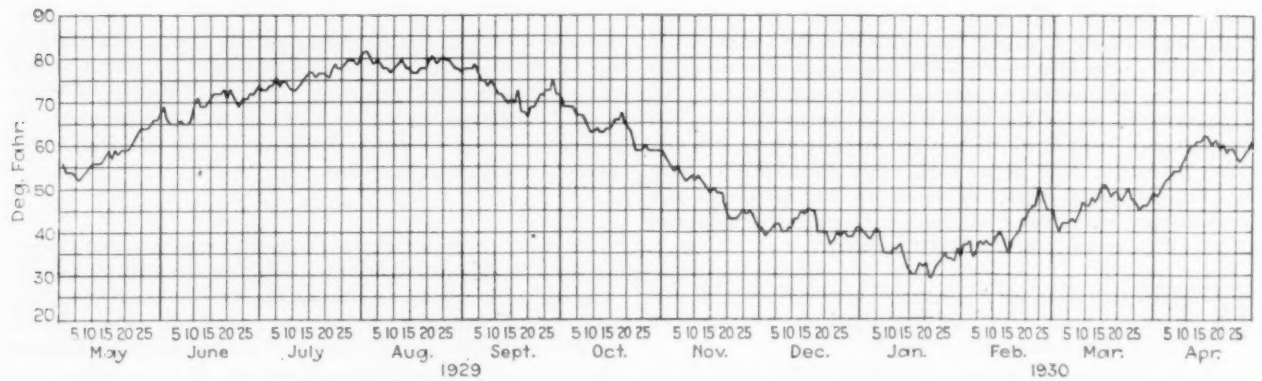


FIG. 2 AVERAGE DAILY TEMPERATURE OF PIPE-LINE OIL STREAM IN THE STATE OF OKLAHOMA

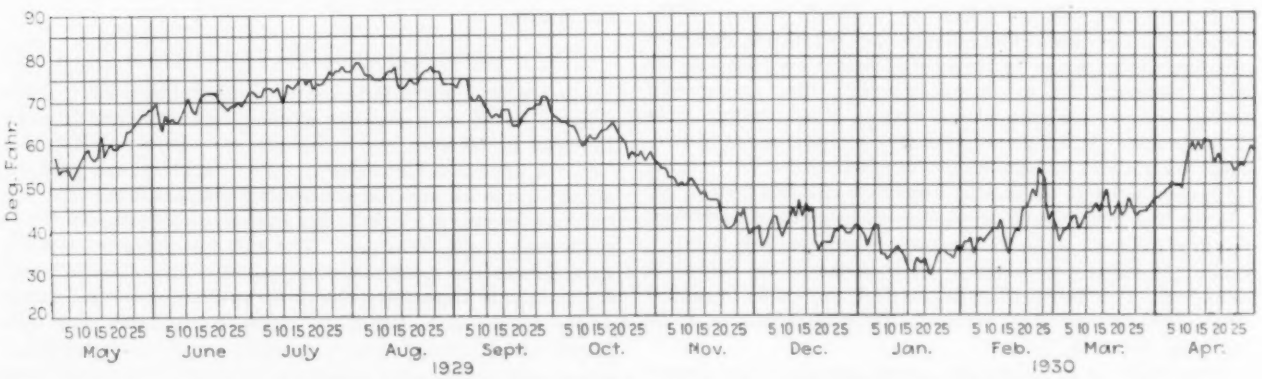


FIG. 3 AVERAGE DAILY TEMPERATURE OF PIPE-LINE OIL STREAM IN THE STATE OF MISSOURI

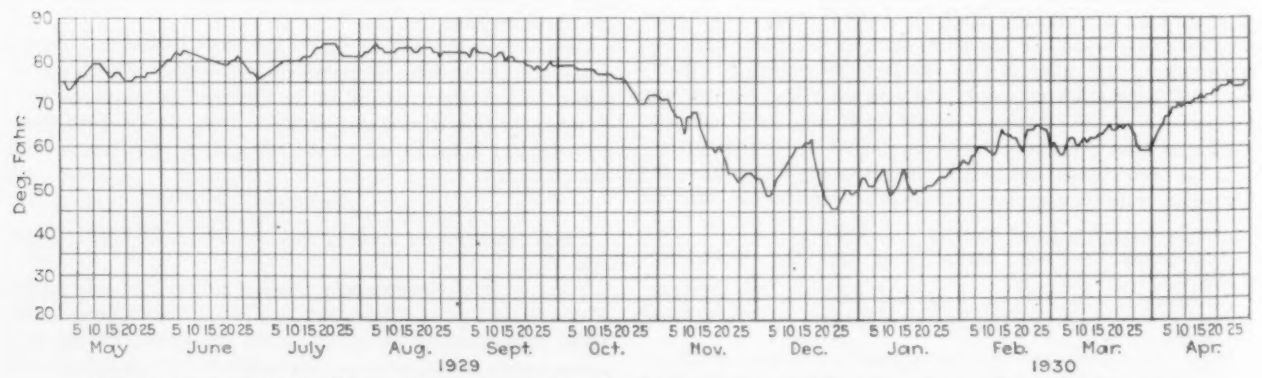


FIG. 4 AVERAGE DAILY TEMPERATURE OF PIPE-LINE OIL STREAM ACROSS THE STATE OF TEXAS, NORTH AND SOUTH

Fig. 2 shows the average temperatures of a non-continuous oil stream received from a trunk line running a little east of north across the central part of Oklahoma and across the southeast corner of Kansas. This curve should give temperatures nearly the same as those that could be expected in oil trunk lines in Oklahoma and Kansas.

Fig. 3 shows the temperatures for an oil stream being delivered in Missouri, near Kansas City. The temperatures on this curve correspond closely with those shown in Fig. 2.

Fig. 4 shows the average daily temperatures for an oil stream flowing through a pipe-line system taking a southeasterly course across the eastern part of Texas and ending at Houston. The temperature shown in this curve should be typical of the oil streams flowing through the principal pipe-line systems of Texas.

Discussion of Results

These temperature observations show that the maximum oil temperatures in pipe lines are reached in Oklahoma, Kansas, Missouri, and Indiana about the first of August and decline to a minimum about the last of January. It appears that the maximum temperature of the oil in the lines in Texas is reached from the middle of July to the first of August, and the minimum temperature is reached about the last of December.

Table 1 shows the maximum and minimum temperatures and the total variation in temperatures from the maximum to the minimum for the various states.

TABLE 1

Location	Maximum temperature, deg. fahr.	Minimum temperature, deg. fahr.	Difference in temperature, deg. fahr.
Illinois and northeast Missouri	71.5	33.5	38.0
Oklahoma and Kansas	79–82	30.0	49–52
Eastern Texas	84	45.5	38.5

The temperatures for the oil stream observed at a point in Kansas and in Missouri are very likely 2 to 3 deg. too high for the maximum and about the same number of degrees too low for the minimum temperature. The reason for these discrepancies is that the stream of oil was not continuous over a 24-hr. period, and consequently during the shutdown period of as long as 16 hours the oil temperature in the line would approach more nearly the ground temperature. The temperature of the oil stream was averaged only for the period during which it was flowing.

These temperature observations show that temperatures as high as 84 deg. fahr. are reached in the oil lines in Texas and that temperatures as low as 45.5 deg. fahr. existed during the last winter (1929–30) in these lines, with a difference of 38.5 deg. fahr. Unusually low temperatures were reached in Texas last winter.

It appears that there is a difference of about 50 deg. fahr. between the maximum and minimum temperatures for the oil streams flowing through the pipe lines in Oklahoma and Kansas, which is nearly 12 deg. higher than the differential for the lines in Texas and Illinois.

The temperature differential for the oil flowing through the lines in Texas is about 38.5 deg. fahr., which is nearly the same for the oil stream flowing through Illinois.

The large drop in the temperature of the oil streams for Oklahoma and Texas on December 17 was caused by the blizzard which set in at this time and which was very unusual for Texas.

These charts show that there are considerable variations in the temperatures of these oil streams over as short a period of time as three to four days. It is during these rapid changes of temperatures in a short period of time that the lines are likely to separate due to the sudden force of contraction.

It is believed that the temperature of the pipe is practically the same temperature of the oil, and this information can be used for studying the contraction of lines.

In no case has artificially heated oil been flowing through these lines during the period of the observations.

There is probably a differential of a degree or two of temperature between the ground and the oil stream.

These curves are presented as an index of temperature conditions for the streams of petroleum flowing through the oil-pipeline systems of the Mid-Continent. These curves show daily averages for only one year. A record for three or four years will be required to establish average annual curves; but these curves should not vary much from the average.

Discussion

F. A. Stivers.[2] As a rough check of data shown in the paper, the writer has compared operating records of temperatures taken in a 12-in. line in Oklahoma, Missouri, and Illinois with readings as shown by these curves. Individual day's readings, of course, show variations from the plotted data, but the general trend of temperatures follows closely enough to indicate that the temperatures shown can be taken as generally representative of other lines in the corresponding states, as well as in the particular line on which readings were taken.

It is interesting to note that oil in the Oklahoma line reached lower winter temperatures than oil in the northern Illinois line, while in summer it reached a peak within a few degrees of the highest temperature found in the line in south Texas. This results in a wider difference between summer and winter capacities in Oklahoma than in Illinois or Texas. For example, in a 12-in. line at 9 lb. per mile friction drop, an oil of about the viscosity characteristic of Seminole crude would flow at a minimum winter capacity rate of $87^1/_2$ per cent of maximum summer capacity in Oklahoma, while under South Texas temperature conditions the minimum winter capacity would be $92^1/_2$ per cent of maximum summer capacity. Due to the lower average temperature throughout the year, the line in Oklahoma would have a total annual capacity only 95 per cent as great as it would have under Texas temperature conditions. On a crude having steeper viscosity curves, such as Oklahoma City crude, the difference between maximum summer capacity and minimum winter capacity would be even more marked than this. These differences must be taken into account in the design of the pipeline system, especially in cases where motor-driven equipment is used, and the information given in this paper should be of much value for such purposes.

In regard to the matter of line breaks, apparently the majority of line breaks due to temperature contraction occur at line temperatures between 30 and 40 deg. and occur at times of relatively rapid temperature changes. It would be of interest in this connection to determine the effect of somewhat greater depth of line burial in smoothing out the sudden temperature changes. The writer would also like to see a line of atmospheric temperatures plotted on the same sheet with the line oil temperatures, so as to know the amount of lag existing in the lines on which readings are made.

[2] General Superintendent, Texas Empire Pipe Line Company, Tulsa, Okla. Assoc-Mem. A.S.M.E.

Some Operating Data for Electric-Motor-Driven Reciprocating and Centrifugal Oil-Pipe-Line Pumps

By W. H. STUEVE,[1] OKLAHOMA CITY, OKLA.

There is interest among operating officials of oil-pipe-line companies in the costs of electric-motor-driven pumping stations, and the author endeavors to give facts on electric energy consumption for both centrifugal and reciprocating pumps. He reaches the conclusion that centrifugal pumps will pump oil at 700 lb. per sq. in. for 0.335 cent per barrel and that reciprocating pumps will do the same work for 0.24 cent per barrel, for the electric power costs.

CONSIDERABLE interest is usually shown by executives of oil-pipe-line companies in the operating costs of an electric-motor-driven pumping station when they are considering the installation of new pumping stations, but authentic data and facts are always hard to obtain, even from a company's own records, to show what the costs actually amount to, for the reason that conditions at particular pumping stations may be different from those which are under consideration.

Some of these conditions are as follows: Electric-motor-driven pumps may operate in parallel with oil engines or steam engines; load factors may be very poor; pipe-line capacity may be too small, causing excessive pressures; or the stations are all oil engine driven, with no electric data available. Consequently, it is necessary to rely on theoretical data, which are not very acceptable.

The purpose of this paper is to present definite electric energy consumption, actual facts, for both centrifugal and reciprocating pumps. The data have been obtained from pipe-line companies, "economy log records."

At the present time there are only a few pipe-line companies which have stations operating at a good capacity factor combined with good electrical load factor, and completely electric motor driven, to provide data for a comprehensive report.

Fortunately, the author has been able to obtain data on fourteen motor-driven centrifugal-pumping stations operating at desirable conditions on a 10-in. pipe line, spaced about 34.5 miles apart. The data cover the average operating results for a year. Likewise the author is able to present corresponding data for four motor-driven reciprocating-pumping stations, operating at desirable conditions on an 8-in. pipe line and spaced about 16.24 miles apart.

[1] In charge of power sales to petroleum industry, Oklahoma Gas and Electric Company. The author, born in Wapakoneta, Ohio, was educated in local high school and later at Notre Dame University, and was graduated from Ohio State University at Columbus in 1908 as Mechanical Engineer in Electrical Engineering. For two years he worked as engineer installing electrical machinery in the paper mills at White Pigeon, Mich., and then for seven years in electrical contracting and consulting engineering at Muskogee, Okla. He served as Ensign, U. S. Navy engineering force, and as Lieutenant (J.G.), U. S. Navy, on the U.S.S. *Mongolia* transport force and the U.S.N.R.F., after which he returned to electrical contracting and consulting engineering at Muskogee. He has been the district power sales engineer, Oklahoma Gas and Electric Co., and then in charge of general power sales, specializing in oil-pipe-line pumping, and now as Power Sales Engineer of the Oklahoma Company.

Presented at the National Petroleum Meeting, Tulsa, Okla., October 6 to 8, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

CENTRIFUGAL PUMP STATION DATA

The centrifugal pumps operated at approximately constant pressure throughout the year, with varying volume. The pumps were throttled during the colder months in order to maintain same pressures. The characteristics of the crude oil pumped are as follows:

Temperature of oil, deg. fahr.	46	50	55	63	70	80
Viscosity, Saybolt Universal, seconds	150	130	110	90	78	70

The lowest average temperature of crude oil pumped was 53 deg. fahr. in February, whereas the highest average temperature was 80 deg. fahr. in August. These readings were actually observed temperatures.

Table 1 shows the compiled average data assembled for each station for the different months in the year. The pressures at the manifold of each station approximated 700 lb. per sq. in.

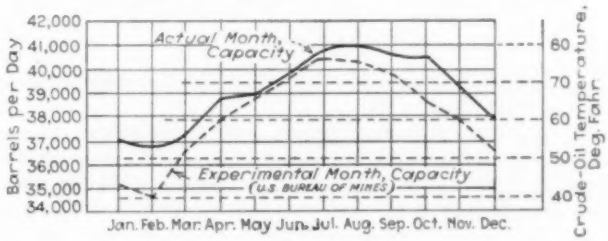


FIG. 1

The pumping units in each station consisted of 400-hp. 1750-r.p.m. induction motors, direct-connected to centrifugal four-stage pumps, each pump unit capable of delivering total volume pumped against 350 lb. per sq. in. Two pump units are connected in series.

TABLE 1

(Constant pressure maintained at the pipe-line manifold, or approximately 20 lb. per sq. in. per mile)

Month	Average barrels pumped per day	Average kw-hr. consumed per 1000 bbl.
January	37,000	338
February	36,700	332
March	37,300	334
April	38,700	340
May	38,900	340
June	39,800	332
July	40,700	317
August	41,000	332
September	40,600	332
October	40,500	325
November	39,200	339
December	37,800	352
Totals for year	14,259,313 bbl.	4,778,437 kw-hr.

From these data the graph shown in Fig. 1 was prepared, with the months of year plotted against barrels per day pumped, as taken from Table 1; also, barrels per day pumped are plotted

against average temperature of the crude oil pumped. It is to be noted how the volume pumped from actual data conforms with the theoretical capacity expected for the temperature of the oil for the given month.

It is interesting to note in Fig. 1 that the actual capacities obtained on this pipe line for different temperatures of the crude oil approximated the theoretical capacities computed with the Bureau of Mines experimental temperature curve for pipe lines buried 2 ft. in the ground in Oklahoma as a basis for the viscosity determination throughout the year.

In order to further check the data given in Table 1 and the data in Fig. 1, where the months of year are plotted against oil temperatures, the curves of the chart shown in Fig. 2 are plotted to indicate that there is a great deal of merit to the observed readings.

The curves are plotted with Universal Saybolt seconds against pounds per square inch per mile pressure drop for given volumes

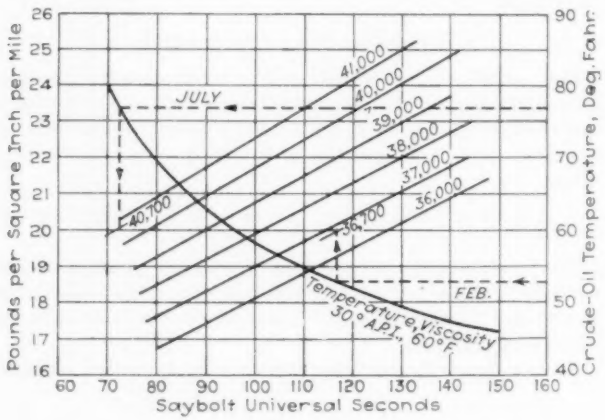


FIG. 2

of oil pumped through a 10-in. pipe line based on approximately 30 deg. A.P.I. gravity oil.

In Fig. 2 the Universal Saybolt seconds are plotted against degrees temperature of oil pumped. It is noted for the month of February, with the average crude temperature of 53 deg. fahr., that the viscosity is 117 Universal Saybolt seconds and that to maintain a constant pressure of 20 lb. per sq. in. per mile the volume pumped will be 36,700 bbl. per day. Correspondingly, the average temperature of the oil pumped in July is approximately 77 deg. fahr., with a viscosity of 72 Universal Saybolt seconds, and the chart indicates further that in order to maintain 20 lb. per sq. in. per mile the volume pumped would be 40,700 bbl. per day. Table 1 and Figs. 1 and 2 show that the theoretical and actual values agree closely.

It is assumed that the foregoing data are approximately correct in all details, since it is known from pressure charts observed at the various stations and also from the characteristics of centrifugal pumps that in order to operate efficiently the pressure maintained by the pump should remain constant throughout the year, which in this case is approximately 700 lb. per sq. in.

Reference to Table 1 shows that the average kilowatt-hour consumed per 1000 bbl. pumped approximates 335, which in terms of electrical input based on pumping an average of 39,000 bbl. per day will represent an average demand of 544 kw. From this electrical input of 544 kw., and assuming electric motor efficiency of 93 per cent, the mechanical efficiency of the pumps is approximately 70 per cent, and is apparently maintained throughout the year.

Reciprocating-Pump-Station Data

Table 2, showing summarized averages, is taken from the "economy log reports" of the individual pumping stations. The data shown in Table 2 are taken from annual records of pump stations containing 500-hp. synchronous motors, 514 r.p.m., geared through reducing gears to 46.25 r.p.m. reciprocating double-acting pumps, triplex, $6^1/_2$ in. by 24 in.

TABLE 2

Station	Days operated	Consumed energy, kw-hr.	Average demand, kw.	Amount actually pumped, bbl.	Average manifold pressure, lb. per sq. in.	Kw-hr. per 1000 bbl.
A.....	301	2,086,500	288.6	9,461,866	643	221
B.....	303	1,962,300	270.0	9,601,356	588	204
C.....	306	2,097,200	285.0	9,580,173	640	219
D.....	294	1,999,960	284.0	9,458,865	605	212

It is noted from the data in Table 2 that the items of electric energy consumption per 1000 bbl. pumped are all proportional to manifold pressures; also, from the demands in kilowatts and average energy consumed and work performed by the pumps, that the average pump mechanical efficiency is approximately 92 per cent.

Conclusions

Since there have been obtained yearly data from both types of pumping units available, and they have been found in keeping with expectancy of line capacities for such operations, and using a cost of 1 cent per kilowatt-hour, it may be said that centrifugal pumps will pump oil at 700 lb. per sq. in. for 0.335 cent per barrel, and that reciprocating pumps will pump oil at 700 lb. per sq. in. for 0.24 cent per barrel for electric power costs only.

Discussion

John M. McGregor.[2] The author shows that the cost for electric power for pumping a barrel of crude oil against a line pressure of 700 lb. per sq. in., using an electrical-centrifugal unit, is 0.335 cent, whereas while using an electrical-reciprocating unit, under the same conditions, the cost of power is 0.24 cent. He gives the approximate mechanical efficiency of the reciprocating pump at 92 per cent and the efficiency of the centrifugal pump at 70 per cent. Little improvement has been made toward attaining nearer perfection in the reciprocating pump during the last four or five years, but strides have been made in increasing the efficiency of the centrifugal pump. The centrifugal pumps cited in the paper are probably three or four years old, and at the time they were purchased, 70 per cent was accepted as being very good. However, recently, percentages of 80 and over are not uncommon. In view of this, the cost per barrel pumped for power would not be 0.335 cent per barrel, but would be 0.285 cent per barrel, or, in other words, modern efficiencies of centrifugal pumps being what they are, the difference in power costs between the reciprocating and centrifugal pump is very much less than shown by the author.

There are some men who, on glancing through the paper in question and seeing these cost figures standing out, would be likely to condemn the centrifugal pump. Although the paper dealt with operating data for Diesel-motor-driven reciprocating and centrifugal oil-pipe-line pumps, it is the writer's feeling that, in fairness to the centrifugal pump, mention might have been made of the purchase price, cost of building, and installation charges, also the time taken to install the different types of units.

It is not the writer's wish to detract in any way from the paper, but merely a desire to bring the questions of efficiencies and overall costs up so that a true comparison might be made.

Author's Closure

It is true the author shows considerable discrepancy between

[2] Byron Jackson Company, Tulsa, Okla. Assoc-Mem. A.S.M.E.

the power cost per barrel pumped of the reciprocating and centrifugal oil-pipe-line pumps.

It is a well-known fact that at this time there are no definite conclusions reached as to the type of equipment to install for main trunk-line stations, and further that some engineers recommend reciprocating pumps and others recommend centrifugal pumps.

The discussor apparently takes the author to task for not setting up the difference in installation costs of the two types of stations. This was taken for granted, as any engineer fully realizes that there is a discrepancy in installation costs, in that the reciprocating stations cost installed perhaps 50 to 75 per cent more than a similar capacity centrifugal station, and that therefore the fixed charges on the increased investment of the reciprocating station would overcome, to a great extent, its lower power costs. Conclusions reached by a great many engineers leave the annual charges for the operation of either type of station an open question, on the assumption that they are approximately equal, and therefore the choice of equipment is entirely up to the likes or dislikes of the engineer in making his design of stations.

The matter of higher efficiencies obtained from centrifugal pumps, mentioned by the discussor, was not available at the time this paper was written, and centrifugal pumps with 80 per cent efficiency, handling crude oil, have been on the market only perhaps for three or four months. The efficiency mentioned, of 80 per cent was obtained on a test conducted for a period of only one day. The original paper deals with average efficiencies obtained over a period of one year.

This higher efficiency of the centrifugal pump as now obtains, namely, 75 to 80 per cent, it is true, will tend to lower the power costs for such an operation; however, the total annual operating charges—after taking into account the fixed charges and maintenance on equipment, and the possibility of decreased efficiencies being obtained over a period of one year, due to sand and other coarse material cutting the impeller, and thereby lowering its efficiency—may again bring such annual operating charges approximately equal to or a stand-off with reciprocating pumps.

PET-52-7

Effect of Hydrogen Sulphide on Wire Rope

By LESLIE W. VOLLMER[1] and BLAINE B. WESCOTT,[2] PITTSBURGH, PA.

Drilling operations in West Texas called attention to the brittleness induced in steel by contact with hydrogen sulphide. This paper is concerned with the investigation of this action on cable tool drilling lines. A sensitive test and the apparatus developed for determining embrittlement in wire are described. The effect of hydrogen sulphide on cold-drawn and annealed plain carbon steels of varying carbon content was determined, and the influence of carbon content and amount of cold work was evaluated. The probable mechanism of the action is explained. The values of several protective metallic coatings were also found.



LESLIE W. VOLLMER



BLAINE B. WESCOTT

ONE of the most interesting of the many new problems which have arisen during the past few years from the rapid expansion in the production of petroleum has to do with the effect of hydrogen sulphide upon the physical properties of steel. The Petrolia pool in Ontario, developed in 1868, was among the first of the sulphide fields. This was followed by others, among which were Trenton, Spindle Top, El Dorado, Kansas, and the Panhandle. It was soon recognized that corrosion of well equipment, gathering lines, and tanks was more rapid in these fields than in the non-sulphide fields, and that failures of parts subjected to repeated stresses while in contact with the gas and oil were somewhat more numerous than usual.

However, it was not until the extensive development of West Texas in 1926, with its gas containing up to 15 per cent by volume of hydrogen sulphide, that its effect on steel was fully recognized. It was manifested by premature failures of apparently sound cable tool drilling lines after but a few hours' service in the pay horizon. The lines became exceedingly brittle; so much so that very often the individual wires could not be bent through an angle of 90 deg. without breaking. Nearly all of these embrittled fractures had a characteristic jagged appearance without any necking, as contrasted to the relatively smooth break of unembrittled, fatigued wire or the smooth diagonal appearance of worn or abraded failures. The type of fracture caused by embrittlement of drilling cable is illustrated in Fig. 1.

It was soon noticed that an embrittled line recovered at least a portion of its original ductility when allowed to remain in the open air for a day or more. This behavior is very similar to that of wire pickled in acid solutions, commonly termed acid or hydrogen brittleness.

The fact has been successfully demonstrated[3] that molecular hydrogen cannot induce brittleness in steel. Atomic or nascent hydrogen, however, rapidly causes brittleness in steel, and it has been generally supposed that the degree of embrittlement was at least roughly proportional to the carbon content.[4] Nascent hydrogen may be generated from the interaction between hydrogen sulphide and steel according to the equation,

$$H_2S + FE \longrightarrow FeS + 2H$$

Occlusion of this freshly generated hydrogen by the wire lines results in embrittlement analogous to that produced in pickling operations, the only difference in the two phenomena being in the method of hydrogen generation. The extreme rapidity with which brittleness can be induced, coupled with the observations that the tensile strength is practically unaffected while ductility is decreased and hardness slightly increased, indicates that the effect is largely a surface reaction. The crystalline character of failures resulting from brittleness justifies the opinion that the atomic hydrogen is absorbed by the intercrystalline material, where it combines to form molecular hydrogen with a change in volume which produces severe boundary strains within the metal.

Embrittlement Testing

Because the maximum effect of hydrogen brittleness is at the surface, the most suitable method for its measurement is by a test in which the greatest stress is at the surface, as for instance, a bend test of some nature. The apparatus devised for the purpose was patterned somewhat after a method previously used[3] to study the effect of caustic on boiler plates. The machine, shown in Fig. 2, consisted of a chuck mounted on a horizontal shaft, motor driven through a single-reduction-gear unit, and connected to a counter at the end of the shaft opposite the chuck. A 3-in. length of the wire to be tested was fastened in the chuck, while the other end passed through a case-hardened bushing mounted in vertical support whose height and distance from the face of the chuck could be accurately measured and varied at will. Throughout this study wire of 0.064 in. diameter was used. The distance from the face of the chuck to the face of the bushing was 1.25 in., and the vertical displacement was 0.25 in. The motor current was controlled by a relay which was actuated by battery current passing through the sample to be tested. Failure of the sample caused the motor to stop.

The number of revolutions to cause failure under these arbitrary conditions was termed rotary endurance, and the ratio of the difference between the rotary endurances of wire exposed to the action of hydrogen sulphide and unexposed wire was called the

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[2] Research Department, The Gulf Companies. Mem. A.S.M.E. Mr. Wescott was born July 7, 1895, at Syracuse, N. Y. In 1917 he was graduated from Syracuse University with the degree of B.S. in Chemistry. He received the degrees of M.S. and Ph.D. from the University of Pittsburgh. For four years he was engaged in research work at Mellon Institute of Industrial Research. Since the organization of the Gulf Research Laboratories three years ago, he has been in charge of the Materials Engineering Division.

Presented at the National Petroleum Meeting, Tulsa, Okla., October 6 to 8, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

[3] P. D. Merica, *Chem. Met. Eng.*, 16, 496–503, 1917.

[4] J. Coulson, *Trans. Am. Electrochem. Soc.*, 32, 237, 1917.

degree of embrittlement. Thus, embrittlement was measured as the per cent decrease in the number of revolutions caused by the exposure to hydrogen sulphide. In all cases, the results reported were the averages of at least five determinations.

The wire samples were treated with hydrogen sulphide, generated from iron sulphide and hydrochloric acid, in flasks interposed between two bubbling flasks containing water in order to assure an excess of hydrogen sulphide at all times. All wires were cleaned

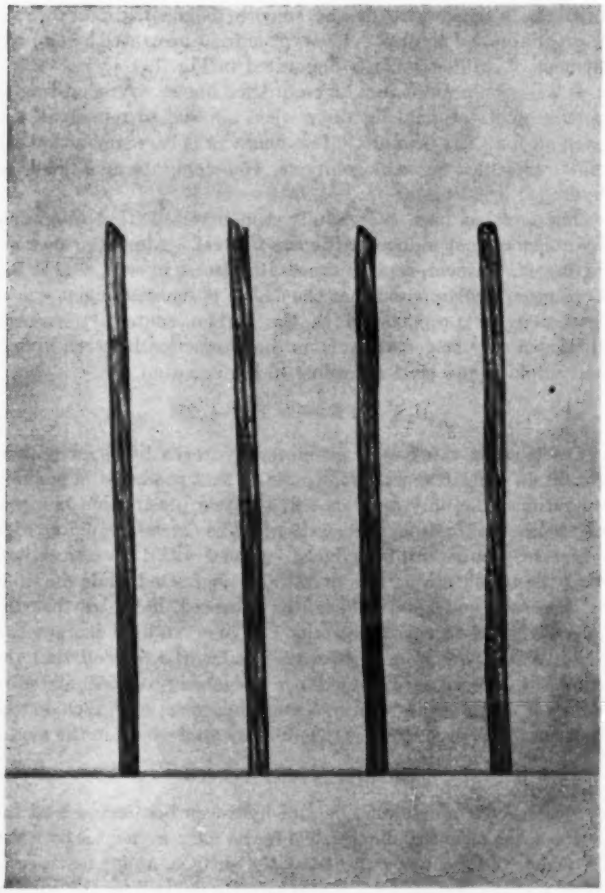


FIG. 1 SERVICE FAILURES OF EMBRITTLED WIRE OF A DRILLING CABLE

in a cold 20 per cent solution of ammonium citrate, washed in cold water, and dried before use.

The effects of hydrogen sulphide were determined for both cold-drawn and annealed wires of varying carbon contents and for

TABLE 1 CHEMICAL ANALYSES AND PHYSICAL PROPERTIES OF PLAIN-CARBON-STEEL WIRES

	Chemical analyses					Tensile strength, lb. per sq. in.	
No.	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Cold drawn	Annealed
339...	0.034	0.030	0.003	0.056	0.017	74,200	39,700
465...	0.386	0.340	0.008	0.040	0.209	180,600	65,600
456...	0.453	0.680	0.005	0.040	0.176	209,600	79,800
458...	0.645	0.580	0.005	0.028	0.239	251,600	86,700
431...	0.688	0.630	0.019	0.061	0.256	242,800	92,200
464...	0.745	0.530	0.007	0.039	0.145	263,300	92,100
468...	0.847	0.330	0.004	0.038	0.260	298,400	103,100
469...	0.918	0.450	0.005	0.025	0.195	315,200	100,000

metallic-coated wires. It was found that wire treated with perfectly dry hydrogen sulphide or immersed in water-free crude oil saturated with the gas did not become embrittled. On the other hand, wire treated with gas moistened by bubbling through water or immersed in well brine saturated with hydrogen sulphide rapidly became brittle.

Table 1 gives the analyses and physical properties of the uncoated wires investigated.

EMBRITTLEMENT OF COLD-DRAWN WIRE

Table 2 gives the results of embrittlement tests made on cold-drawn plain carbon steel wires of varying carbon contents. In

TABLE 2 PER CENT EMBRITTLEMENT OF COLD-DRAWN PLAIN-CARBON-STEEL WIRES

(A) Wires Treated With Moist Hydrogen Sulphide

Hours exposed	Per cent carbon content							
	0.034	0.386	0.453	0.645	0.688	0.745	0.847	0.918
4....	..	59.9	54.7	58.0	69.5	58.1	100.0	100.0
8....	..	46.4	50.2	45.6	53.8	76.1		
16....	..	59.3	50.3	44.4	63.3	79.3	Samples	
24....	50.9	64.9	47.2	29.4	69.9	48.6	ruptured	
48....	47.8	62.7	45.6	33.8	62.4	45.1	spontaneously	
72....	51.9	62.3	37.8	21.7	59.7	46.7		
96....	52.6	60.2	34.9	18.9	56.4	19.5		
120....	40.2	54.3	27.7	18.7	53.4	33.5		

(B) Wires Immersed in Oil-Well Brine Saturated With Hydrogen Sulphide

Hours exposed	Per cent carbon content							
	0.034	0.386	0.453	0.645	0.688	0.745	0.847	0.918
4....	31.7	48.9	39.4	51.6	59.8	42.7	100.0	100.0
8....	31.7	46.5	36.5	47.6	59.5	44.2		
16....	45.4	35.0	36.3	37.1	57.2	44.6		
24....	69.9	63.3	57.6	44.2	64.4	54.1	Samples	
48....	70.3	59.8	54.6	40.6	67.9	49.6	ruptured	
72....	66.8	57.5	48.1	20.4	59.3	28.1	spontaneously	
96....	68.9	56.3	47.7	18.1	62.9	36.5		
120....	65.5	41.2	37.2	17.1	55.9	11.1		

most cases, the figures in the table represent the averages of at least three separate experiments under the stated conditions. The variations shown were due to two causes: (1) The rotary endurance test is extremely sensitive to any inhomogeneities in surface conditions or internal composition, and (2) there are greater relative variations in the size and the physical make-up of small wire than in specimens of greater cross-sectional area.

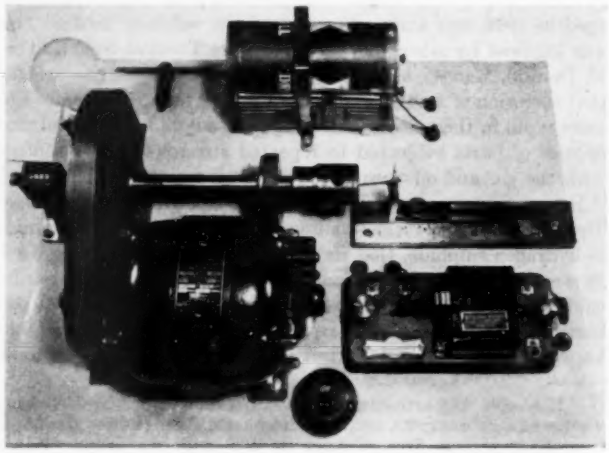


FIG. 2 WIRE-EMBRITTLEMENT-TESTING MACHINE

In addition, practically all of the wire used in this investigation was made in small lots especially for this purpose, thus introducing greater differences in uniformity than commonly occur in commercial wire.

The rates of embrittlement were somewhat slower in the samples immersed in brine, although the maxima were practically the same. With each grade of wire a maximum was reached after which the embrittlement decreased. This action was similar to that found with caustic and boiler plate.[3] It may be explained in this instance by the fact that the formation of atomic hydrogen was dependent upon the hydrogen sulphide coming into contact with the steel. As the reaction progressed, a coating of iron sul-

phide was formed upon the surface of the steel, and the rate of diffusion of hydrogen sulphide into the surface constantly decreased. Finally, this rate of diffusion became less than that of the occluded gas from the steel, and the embrittlement consequently decreased.

The similarity between failures from embrittlement in service and in this investigation is illustrated by a comparison of Figs. 1 and 3. The same angular type of fracture occurred in nearly every instance. The cause of this type of break will be made clear later. The 0.034 per cent carbon wire (ingot iron) behaved in a very irregular manner throughout. If this material is disregarded, there is a qualitative relation between the carbon content and degree of embrittlement—the latter increased as the former. It will be shown later that this was not a true relation. The wires containing more than 0.75 per cent carbon ruptured spontaneously after three hours' exposure to hydrogen sulphide.

Wires ruptured in this manner are shown in Fig. 4. In some cases the 0.75 per cent carbon wire also split. The cracks started in a direction nearly perpendicular to the surface of the wire, and after penetrating for about one-third of the diameter, proceeded in a longitudinal direction. The intercrystalline character of the cracks is evident from Figs. 5 and 6.

It was quite certain from this that the action of the sulphide gas caused rupture by intensifying previously existent internal stresses—quite logically, the stresses engendered by the cold-drawing operations of manufacture. The angular character of the embrittled failures was caused by the tendency to follow these longitudinal lines of internal stress.

Furthermore, it seemed probable that there was no direct relationship between carbon content and degree of embrittlement. The draft or reduction of cross-sectional area in cold drawing of wire is very nearly the same for steel of all carbon contents when

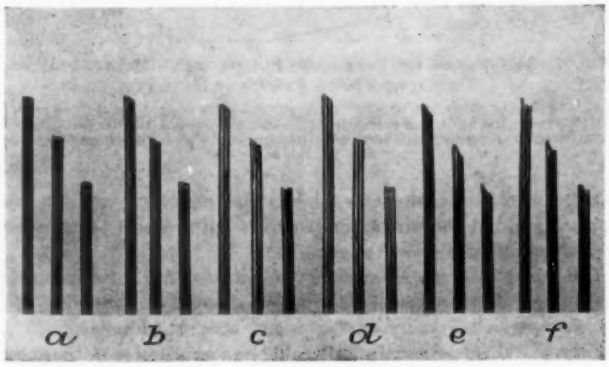


FIG. 3 FRACTURES OF EMBRITTLED COLD-DRAWN CARBON-STEEL WIRES

(*a*, 0.034 per cent carbon; *b*, 0.386 per cent carbon; *c*, 0.453 per cent carbon; *d*, 0.645 per cent carbon; *e*, 0.688 per cent carbon; *f*, 0.745 per cent carbon.)

maximum strength is sought. High-carbon steels are less ductile than the lower-carbon steels, and when subjected to the same amount of cold work, the internal stresses resulting are much greater.

The apparant relation between carbon content and degree of embrittlement was then primarily a relation between internal stress or cold work and degree of embrittlement.

The speed with which hydrogen sulphide can cause embrittlement affords a very interesting line of investigation. This was determined for the 0.688 per cent carbon steel, which was a commercial grade of improved plow steel for drilling lines. The embrittlement increased steadily from 20.4 per cent in 15 min. to a maximum of 69.8 per cent in 3 hr. It no longer seems strange that failures occur after a short time in lines exposed to hydrogen sulphide while subjected to severe repeated stresses.

Samples of the same wire were treated to produce maximum brittleness, and were then allowed to stand in the open air for 24 hr. The original degree of embrittlement decreased from 70.0 per cent to 12.8 per cent. At the end of seven days the embrittlement had dropped to 6.4 per cent, representing a recovery of 90.9 per cent of the ductility lost. Similar results can be effected in shorter times by heating. Systematic periods of rest or recovery would materially increase the life of uncoated steel drilling lines in sulphide fields.

The recovery is quite simply explained by the formation of molecular hydrogen and its diffusion from the steel.

EMBRITTLEMENT OF ANNEALED WIRE

In order to verify the foregoing reasoning with direct evidence, brittleness tests were carried out on samples of the same wires after dead-soft annealing. These results are given in Table 3.

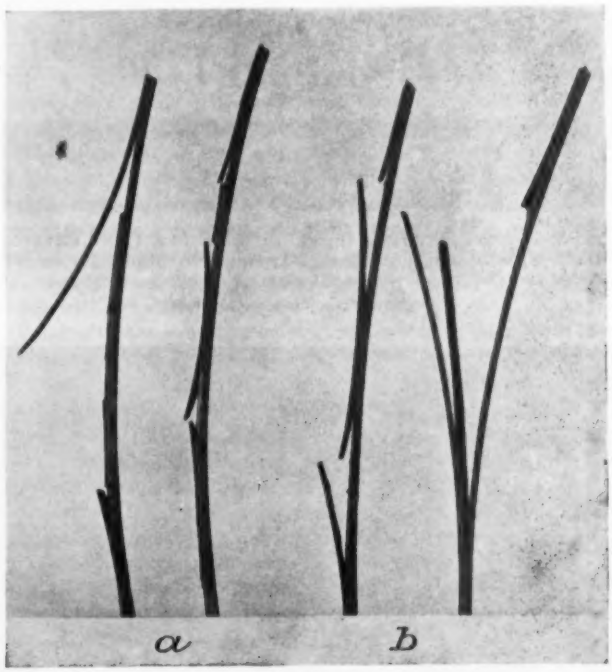


FIG. 4 SPONTANEOUS RUPTURING OF HIGH-CARBON STEEL WIRES AFTER EXPOSURE TO MOIST HYDROGEN SULPHIDE

(*a*, 0.847 per cent carbon; *b*, 0.918 per cent carbon.)

TABLE 3 PER CENT EMBRITTLEMENT OF ANNEALED PLAIN-CARBON-STEEL WIRES

(*A*) *Wires Treated With Moist Hydrogen Sulphide*

Hours exposed	Per cent carbon content							
	0.034	0.386	0.453	0.645	0.688	0.745	0.847	0.918
4....	64.7	15.5	32.5	12.7	25.2	29.2	18.2	13.0
8....	57.7	42.4	40.5	27.0	24.5	32.1	21.2	19.4
16....	79.0	15.4	30.4	16.1	18.7	31.8	7.5	7.6
24....	63.4	29.8	30.3	22.9	13.8	15.9	17.2	10.0
48....	63.0	34.7	27.5	20.6	12.9	30.9	18.9	8.7
72....	60.3	28.3	29.4	17.0	16.0	29.3	18.4	9.6
96....	62.8	25.1	15.9	16.8	11.7	21.8	16.5	8.6
120....	66.9	18.4	14.9	22.4	20.4	29.1	12.5	6.9

(*B*) *Wires Immersed in Oil-Well Brine Saturated With Hydrogen Sulphide*

Hours exposed	Per cent carbon content							
	0.034	0.386	0.453	0.645	0.688	0.745	0.847	0.918
4....	46.6	39.4	35.1	27.9	10.4	32.1	21.7	22.0
8....	43.2	16.7	35.3	20.2	26.2	29.5	26.0	27.9
16....	64.0	29.0	31.8	29.0	23.1	19.4	31.4	34.4
24....	62.0	43.4	44.7	32.5	33.6	33.8	23.4	28.3
48....	67.0	33.1	34.9	28.4	27.4	30.3	18.8	23.3
72....	67.1	22.5	34.9	19.2	14.4	27.6	18.5	17.0
96....	68.2	26.2	27.5	22.5	19.1	28.5	19.3	15.7
120....	71.3	14.7	19.5	11.2	14.4	15.8	19 9	14.4

The elimination of internal stresses was forcefully reflected by the type of fractures obtained. It is clear from Fig. 7 that

the angular breaks were obtained only from cold-drawn wire. As predicted, with the exception of the ingot-iron wire, the maximum embrittlement of the annealed samples was much less than that found with cold-drawn wires. There was an inverse relation between carbon content and degree of embrittlement, the higher carbon wires embrittling less than the lower. From this

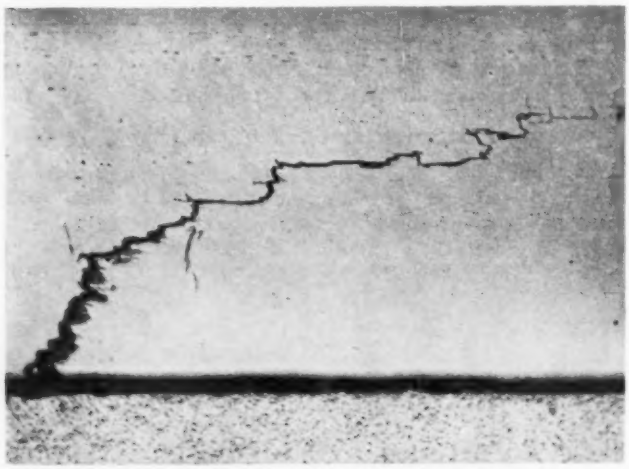


FIG. 5 INTERCRYSTALLINE CRACK IN 0.745 PER CENT CARBON-STEEL WIRE RESULTING FROM EXPOSURE TO MOIST HYDROGEN SULPHIDE
(Unetched; magnification, 75 times.)

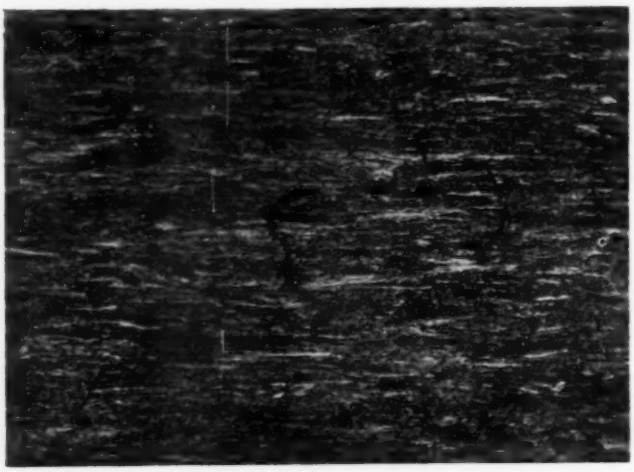


FIG. 6 INTERCRYSTALLINE CRACK FOLLOWING FERRITE GRAIN BOUNDARIES IN 0.745 PER CENT CARBON-STEEL WIRE RESULTING FROM EXPOSURE TO MOIST HYDROGEN SULPHIDE
(Etched; magnification, 460 times.)

it was concluded that the occlusion or absorption of atomic hydrogen increases as the purity of the iron, or, strictly speaking, the ferrite increases. The ingot iron, being nearly carbon free, is essentially pure ferrite, while in the steels containing carbon, the intergranular material, being the last to solidify, has a higher melting point, and is therefore ferrite of greater purity.

These conclusions explain the angular fractures of the cold-drawn carbon-steel wires and their absence in the case of the ingot iron.

TABLE 4 PER CENT EMBRITTLEMENT OF METALLIC-COATED STEEL WIRES IN MOIST HYDROGEN SULPHIDE

Hours exposed	Protective metallic coating				
	Tin	Copper	Lead	Zinc A[1]	Zinc B[2]
24	74.0	+ 7.0	1.0	3.8	7.2
48	82.0	4.5	2.8	1.3	45.0
72	86.1	+ 7.0	8.6	6.3	45.7
96	86.3	+14.8	8.9	3.2	69.5
120	87.8	+13.5	+8.0	0.0	63.1

[1] Ordinary galvanized drilling wire.
[2] Special galvanized drilling wire with very thin coating.

PREVENTION OF EMBRITTLEMENT

The most obvious method of combating embrittlement is by the use of protective coatings to prevent contact between the hydrogen sulphide and the steel.

The values of several common metals for the purpose were determined, with the results given in Table 4.

In consideration of these results it should be pointed out that the tests were of short duration and none of the coatings was tested to destruction, excepting the tin and the zinc B. The tin afforded practically no protection; zinc B gave partial protection for three days. Zinc A and lead furnished excellent protection

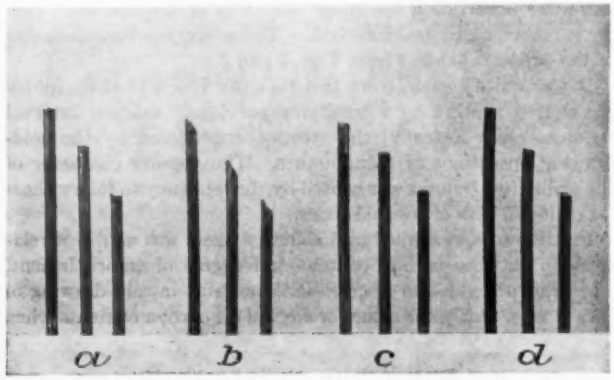


FIG. 7 FRACTURES OF IMPROVED PLOW-STEEL DRILLING WIRE, CONTAINING 0.688 PER CENT CARBON
(*a*, cold-drawn wire not exposed to hydrogen sulphide; *b*, cold-drawn wire exposed to moist hydrogen sulphide for 24 hours; *c*, annealed wire not exposed to hydrogen sulphide; *d*, annealed wire exposed to moist hydrogen sulphide for 24 hours.)

for the total time of the tests, while copper not only gave complete protection, but the wire actually gained with respect to its initial rotary endurance strength.

The results given by ordinary galvanized drilling wire agree with field experience. In the early days of drilling in West Texas it was customary to start a new black steel line at the top of the pay. If possible the well would be completed with the same line and another started. Usual service averaged less than one well per line. It is now general practice to use galvanized lines for drilling in all wells. Uncoated lines are used to top the pay.

Galvanized lines so used average five or more wells before it becomes necessary to discard them. They are unsuited to ordinary drilling, however, because of their lower strength and resistance to abrasion. Very substantial economies in both time and expense have resulted from their use in the manner outlined. A test of a copper-clad drilling line in this area would be of considerable interest.

Further tests on wire coated with a light grease have given much less embrittlement, indicating that frequent lubrication of drilling lines would lessen their susceptibility to embrittlement. Any chemical treatment of the lubricating oil which would keep the steel preferentially wet with oil rather than water would be of real value also.

Additional experiments are now in progress on other coatings, alloy steels, and the effects of hydrogen sulphide on other physical properties of steels.

Conclusions

1 A sensitive method has been developed for determining the degree of embrittlement in steel wire.

2 Plain carbon steels become rapidly embrittled when subjected to the action of moist hydrogen sulphide.

3 The embrittlement is caused by the absorption of atomic hydrogen formed from the reaction between hydrogen sulphide and iron.

4 In cold-worked plain carbon steels the degree of embrittlement is proportional to the amount of cold work and has no relation to the carbon content.

5 In dead-soft annealed plain carbon steels the degree of embrittlement is inversely proportional to the carbon content.

6 Absorption of atomic hydrogen occurs mainly in the purest ferrite—i.e., intercrystalline material of carbon steels and more or less uniformly throughout pure iron.

7 Steel wire embrittled by hydrogen sulphide recovers nearly all of its original ductility after standing for a time or by a gentle baking for a few hours.

8 The life of uncoated steel drilling lines in sulphide fields may be substantially increased by systematic periods of rest or by heating to 400 deg. fahr. for three hours.

9 Embrittlement may be prevented by various protective metallic coatings or other materials which prevent hydrogen sulphide from coming into contact with the steel.

10 Galvanizing has been shown to form an excellent protective coating, both in the laboratory and in actual drilling service.

11 Lead and copper coatings appear to possess protective ability against sulphide embrittlement, but tin is worthless.

Acknowledgments

The authors wish to express their appreciation to the Williamsport Wire Rope Company, the Hazard Wire Rope Company, and the Broderick & Bascom Rope Company for samples used in this investigation.

Also they acknowledge the aid of Mr. F. J. Reed and Mr. S. J. Edge, of the Gulf Laboratories, in the experimental work carried out.

Discussion

Dudley R. Dale.[5] This discussion will be confined to the conclusions reached and their application to sucker-rod failures. The writer did not feel justified in discussing wire lines as his entire interest is in the manufacture and use of sucker rods. However, the conditions under which both sucker rods and drilling lines work and fail are similar.

Three thoughts occur. First, hydrogen-sulphide embrittlement of steel oil-field equipment is not a new problem, but rather a relatively unknown one, comparatively recently discovered. Second, there is a similarity of the duties of drilling lines and sucker rods, both being subjected to alternate and reciprocating repeated high stresses and operating in the presence of hydrogen sulphide gas. Third, there is little information available concerning this type of equipment failure.

The paper throws much light on this puzzling subject and gives the metallurgist and designer data which he can feel justified in safely using.

Sucker rods, unlike wire lines, are not manufactured of cold-worked material. The best present practice in the manufacture of sucker rods is to use hot-rolled steel, and after the necessary forging operations are completed, they are given a complete normalizing heat treatment. This is done to remove local heat demarcations, forging strains, and to refine and make uniform the micro-constituents. They are therefore initially in a condition of strain equilibrium. The results shown by Table 3 will therefore more aptly apply to sucker rods.

Sucker rods are usually made of straight carbon steel, the carbon varying from 0.30 to 0.55 or 0.60 per cent, with the manganese varying from 0.50 to 2 per cent, the phosphorus and sulphur being 0.04 per cent maximum.

For many years rod manufacturers and producers were puzzled by premature failures, which could not be explained by an analysis of the pumping loads and their relation to the physical properties of the steel of which they were made, notwithstanding that this analysis showed a somewhat high factor of safety. Nor did a study of crooked holes, tight or sanded working barrels, inertia loads, etc., explain some of the failures which it is now known were caused by hydrogen-sulphide embrittlement. One example of this condition remains fixed in mind. In a certain West Texas well, new rods of one make started to break at the end of four days after installation. Other makes started to break in from 10 days to two weeks after installation. Pumping loads, speed, size of tubing, and depth of pump were studied, and the rods had a factor of safety in physical properties which should have given reasonable performance. Analysis of the fluid, however, showed a high content by volume of hydrogen-sulphide gas.

Rods taken from this well showed the typical progressive fatigue fracture invariably found on most rod failures, these fractures being smooth and silky for approximately half of the cross-section and somewhat coarse and crystalline for the remainder. All of these fractures are approximately at right-angles with the axis of rod.

Some of these rods, immediately upon being pulled from the well, were given a bend test by bending them around the derrick leg, and much to one's surprise did not bend more than 40 to 50 deg., breaking with a brittle snap and showing a crystalline fracture. New rods could be cold bent 180 deg. without fracture.

Samples of these prematurely failed rods were then sent to the laboratory for examination. Chemical analysis was up to standard and did not reveal a possible cause of the trouble. Physical tests also showed the material to be up to standard, the Brinell test showing only a slight increase in hardness. Microscopic study was also made. After laboratory examination failed to reveal any satisfactory answer to the problem or to show any fault with the material, some of the broken rods, which in the meantime had laid on the ground for about ten days, were again given the same bend test, with results pleasingly satisfactory. The steel had now almost recovered its former ductility.

The conclusion then was reached that the steel was absorbing something which had an embrittling effect as long as it was in contact with the fluid in the well, but which was self-purged if given a period of rest or other natural treatment. As examination of the fluid revealed a high content of hydrogen-sulphide gas, and as it was well known that steel was embrittled by hydrogen, it was justly concluded that the answer to the problem had been found. It also was revealed why laboratory tests did not give the answer, as the samples had opportunity to purge themselves of the hydrogen during the time they were going to the laboratory and awaiting testing.

Some manufacturers and producers in the past have advocated a rest treatment for rods, some even going so far as to recommend an annealing treatment, the thought being that the rods were in a highly strained condition due to the work they performed. They were thought to be in a condition similar to what is known as Stead's brittleness. As is well known, Stead's brittleness occurs only in steel of low carbon content (under 0.15 per cent) where they have been subjected to temperatures of 900 to 1400 deg. fahr. for long periods of time, and which action resulted in an enlarged grain growth. Sucker rods, being made of 0.30

[5] S. M. Jones Co., Toledo, Ohio.

to 0.60 carbon steel and not being subjected to any such temperature, could not of course be in that condition.

It is also the opinion that many sucker-rod failures can be attributed to varying degrees of sulphide embrittlement, the time of the commencement of such failures depending upon the degree of gas present.

The conclusion therefore has been reached that, where premature failure of sucker rods occurs due to hydrogen-sulphide embrittlement, the steel will recover nearly its original ductility if allowed to rest in the open air and sunlight for comparatively short periods of time, and as the authors have stated, this can be made more complete by a gentle heat treatment.

There is danger, however, in giving sucker rods an oil-field heat treatment; improper equipment and supervision might result in unequal heating. Under proper conditions of heating and supervision it should be beneficial.

Where rods have been in service long enough to start fatigue fractures no heat treatment (exclusive of welding) or rest will repair the damage. The rest cure, only, is advocated to remove hydrogen, the cause of embrittlement.

The writer agrees with the authors that embrittlement in annealed or normalized steels is inversely proportional to the carbon content, and is caused by the absorption of atomic hydrogen formed from the reaction between iron and hydrogen sulphide. The mechanism of the embrittling action is, first, the reduction of oxide by the hydrogen forming water which causes a swelling at the grain boundaries. This increase in volume, in turn, creates a stress, which, added to the pumping stress, causes the rupture.

The authors have constructed a testing machine which in theory and in practice should give results that can be relied upon. A bend test is first a test of the surface of the material, where the maximum effect of the embrittlement is encountered. The combined rotating and bending of the test specimen reacts on all points of the circumference where bending is concentrated.

While the authors have been able to test individual wires of the complete wire line, this procedure is not followed in the testing of sucker rods. Small test samples, made to fit the standard Moore rotating fatigue machine, are used instead.

In conclusion it is desired to state that physical, chemical, and microscopic tests do not reveal hydrogen embrittleness. Immediate bend tests upon pulling the rods from wells, and comparison with later tests after rods have been rested or treated, are very often conclusive.

In regard to protective coatings, it has been found that certain paints have resulted in improved performance rods, but the effect can be considered as only temporary and probably not worth the expense.

Zinc galvanizing seems to slightly improve performance, but is not an ideal coating, as it has a tendency to flake, especially if the rods are stressed beyond the elastic limit of the steel.

It is also the opinion of some operators who have extensively used galvanized rods that the extra cost did not compensate them for the slight increase in service given over black or ungalvanized rods and that it is a temporary cure at the most.

Leadized rods are now being tested, and from the conclusion of the authors, should show good performance.

While this discussion on hydrogen-sulphide embrittlement of sucker rods is rather apart from the paper, the results obtained and the conclusions reached by them were so clearly applicable to sucker rods that it was felt that the paper is doubly valuable.

H. W. Fletcher.[6] The authors have attacked a problem which is of increasing importance to the oil industry, particularly the producing departments, and to the manufacturer of drilling and production equipment. Broadly the action of hydrogen sulphide on steel is in effect an "etch" of the surface producing a weak brittle coating of iron sulphide and liberating nascent hydrogen. This being absorbed into the structure of the metal combines to form a molecular gas, thus building up high internal pressures, adding to the stresses already present, and causing local failure where critical values are exceeded. The deleterious effect of such flaws, acting as they do to produce stress concentration out of all proportion to the actual reduction in coherent cross-section, can hardly be overemphasized.

It should be noted that two separate and distinct results follow the exposure of steel to a moist hydrogen-sulphide atmosphere. The original surface is destroyed, and the action is preferential due to chemical inhomogeneity, thus roughening the surface. That this in itself results in lower fatigue resistance is indicated by experience with fatigue specimens where the degree of mechanical finish influences largely the fatigue limit, the rougher specimens showing the lower values. On the other hand, whereas surface roughness does not within reasonable limits affect static strength, exposure to moist hydrogen sulphide will cause spontaneous rupture of steel parts where internal (static) stress exists due to previous cold working. As surface finish is not in this case of prime importance, increase of stress due to absorption of hydrogen is the logical explanation of failure.

That hydrogen penetration progresses most rapidly along grain boundaries is fairly certain. At least, the fact that the cracks develop there indicates that the resultant pressures exist mainly at grain boundaries; and experience with other gases such as carbon monoxide and oxygen has demonstrated a more rapid penetration along grain boundaries. It does not seem, however, that the evidence presented offers sufficient grounds for the conclusion stated in the paper that "The intergranular material, being the last to solidify, has a higher melting point, and is therefore ferrite of greater purity."

Relatively pure ferrite, to be sure, has the higher melting point, but because of this fact is the first to solidify from a melt, and the last material to freeze is of higher carbon concentration. The resulting structure consisting of austenitic grains undergoes a secondary crystallization as the temperature falls, resulting, where cooling is slow, in the formation of an aggregate of ferrite and pearlite grains, jointed by an intercrystalline material of undetermined composition. Since the intergranular material is mainly a product of secondary crystallization, it seems unlikely that its composition is a function of melting point in view of the fact that the grain boundaries existing after secondary crystallization are not in general those boundaries formed in the freezing of the melt.

It is true that the lower the carbon the more nearly continuous is the network of ferrite grains and the more completely this network encloses the pearlite grains, from which it might be argued that the hydrogen is absorbed principally by the ferrite grains in mass. On the other hand, there is reason for concluding from results with other gases that penetration is mainly along grain boundaries rather than the body of the grain.

Any explanation of the relation of degree of corrosion embrittlement to carbon content must necessarily depend in its conclusions to a degree at least on the reaction assumed to take place after the atomic hydrogen has entered the metal. Suppose for instance that only part of the atomic hydrogen reverts to the molecular form and the balance combines with carbon drawn from the carbides present, forming perhaps hydrocarbons of the methane series. With a given amount of hydrogen taken in, it might with reason be argued that the resultant pressure maximum might be lower than where all the hydrogen reverted to the molecular form. On the other hand, this would require

[6] Chief Engineer, Hughes Tool Company, Houston, Texas. Mem. A.S.M.E.

that the rate of diffusion of the hydrogen-hydrocarbon mixture be not too much lower than that of molecular hydrogen alone, since the pressure maximum must obviously be the result of the difference between rate of input and rate of loss. Should this be the case it would be reasonable to expect that in the annealed state high-carbon steels would show less damage than low-carbon steels because of the greater proportion of hydrogen going to form hydrocarbons, resulting in lower gas pressures, whereas in the cold-worked condition the residual stress increase with higher carbon might be great enough to overbalance the reduction in maximum gas pressure attained, such a relation explaining the results of the authors' experiments. In this connection it might be mentioned that it has been demonstrated that high-

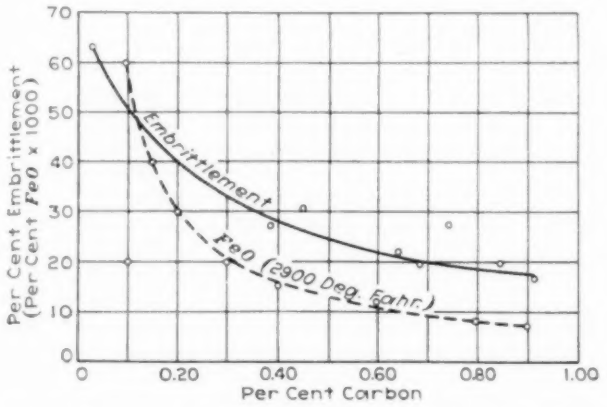


FIG. 8 RELATION OF HYDROGEN-SULPHIDE EMBRITTLEMENT TO DISSOLVED OXIDE CONTENT IN ANNEALED WIRE

(Note: Per cent of embrittlement values are averages of authors' figures for all tests of a given carbon content in annealed samples.)

carbon steel heated in a hydrogen atmosphere loses its carbon (presumably as hydrocarbons), but the assumed reaction between atomic hydrogen and iron carbide at room temperature (but possibly at higher pressure and in the presence of catalysts) is so far without experimental verification. Acceptance of such a theory would avoid the necessity of postulating an intergranular material composed of pure or nearly pure ferrite.

Still another possible explanation of the phenomenon has been suggested by R. W. Schlumpf, metallurgist for the Hughes Tool Company. If the authors' values for decrease in fatigue resistance and C. H. Herty's values for oxygen concentration in steel are plotted on the same sheet against carbon content as abscissa, two curves result similar in form and for some distance closely parallel. (See Fig. 8.) This suggests the correspondence of degree of corrosion damage with the amount of oxides in solid solution in the metal rather than an inverse relation to the carbon. If we assume that part of the atomic hydrogen combines with oxygen to form water, we might expect high pressures to develop due to the inability of the water molecule to diffuse from the structure. A reaction of this nature is encountered when copper is heated in a hydrogen atmosphere, resulting in the production of internal flaws presumably from the reaction of hydrogen with the oxide content of the metal. Recovery is perhaps more difficult to explain on this theory, but might be due to diffusion of that part of the hydrogen not combined as water, in which case recovery should probably be less complete with the lower carbon material.

Several years ago the writer observed some phenomena that are of interest in connection with the subject of this paper. Samples of boiler plate were boiled for three hours in 40 per cent hydrochloric acid, and were then sealed in a nickel container and baked for 50 hours at 1850 deg. fahr., after which they were cooled and removed from the container. The surface of the samples initially rough polished was found after baking to be distinctly matte in finish and at 40 diameters magnification resembled coarse pumice stone, while an initially pure nickel target placed about $^1/_8$ in. from the plate analyzed, after baking, 10 per cent iron. There was clear evidence to show that minute bubbles of gas burst through the surface of the specimen, driving off particles, some of which impinged on and alloyed with the target. Small pimples were found on the specimen where bubbles of gas were about to break through when heating was discontinued. Samples baked without previous boiling in acid showed no apparent surface change except that due to the small amount of oxidation attendant upon the process of baking. It was noted that samples polished after the acid treatment and baked for a shorter time showed a clear development of the grain boundaries, indicating that the gas traveled mainly along the boundaries, but also to some extent through the structure of the grains themselves.

The authors' work on protective metallic coatings is most interesting, particularly in respect to the failure of tin and the marked success with copper. The latter has long since proved its usefulness in a similar situation, but at elevated temperatures, where it is desired to prevent carburizing of certain portions of pack-hardened work which are plated before packing, the copper "sealing the pores" and preventing the entrance of the carburizing agent, probably chiefly carbon monoxide. The results of commercial applications of protective coatings in service as recounted by the authors are most encouraging, and it is perhaps not too much to hope that means may be discovered to incorporate the protecting elements into the surface layers of the steel, as for instance in the calorizing of steel with aluminum, thereby extending this protection to such products as are exposed to abrasive wear too severe for surface coatings.

AUTHORS' CLOSURE

The authors are greatly appreciative of the interest expressed in this problem by Messrs. Dale, Fletcher, and Schlumpf. The mechanism of hydrogen occlusion and the resultant embrittlement of steel, whether it be caused by acid pickling or exposure to hydrogen sulphide, is undoubtedly identical and has been the subject of several hypothetical suppositions. The explanation offered that the embrittlement is caused by the formation of water from the reaction of hydrogen with occluded oxygen or metallic oxides should be capable of demonstration by the use of steels containing determined amounts of both gaseous oxygen and metallic oxides. If the formation of water is the determining factor, then steels poor in oxygen content should be less susceptible than those containing larger amounts. The similarity of the curves pointed out by Mr. Schlumpf is interesting and suggests a very promising line of investigation. However, higher-carbon steels might generally be expected to contain less oxygen than low-carbon steels or iron. In either case the damage resulting from the formation of water might probably be of a more or less permanent nature, making it difficult to explain the almost complete recovery.

The postulation of the formation of hydrocarbons seems to agree more fully with the recovery effects noted. The rapidity with which embrittlement can be caused by pickling indicates a high rate of reaction seemingly more consistent with the formation of molecular hydrogen than with a chemical reaction involving the formation of hydrocarbons from the decomposition of metallic carbides. The effect may be the resultant of all three theories offered. It is the expressed hope of the authors that subsequent experimentation will indicate the true mechanism of the phenomenon. It is suggested that an X-ray study of embrittled steel might go far in the solution of the problem.

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Economic Design of Oil-Pipe-Line Transportation Systems

By OSCAR WOLF,[1] HOUSTON, TEX.

Carriers of energy and transportation systems for gas or oil should be so designed that the sum of their total yearly charges (fixed charges plus all operating expenses) is a minimum. This paper presents the basic cost data entering into the design of an oil-pipe-line system as a function of the known quantites, usually given in the form of:

(1) The permissible maximum working fiber stress of the steel in pipe
(2) The physical characteristics of the oil to be transported
(3) The length of the prospective line
(4) Elevation of initial and terminal points of the system
(5) Daily capacity for which the system is to be designed
(6) Period of years during which all non-salvageable investments are to be retired by a proper depreciation reserve
(7) Interest, depreciation, and tax, and insurance rates.

It is possible to express the total pressure heads to be overcome, and consequently the power requirements of such a system, as a function of these given terms. The resulting equation, representing the sum of the fixed charges and operating expenses Y + X, can then be differentiated, and by making the first differential coefficient equal to zero, the most economical pipe diameter, pipe-wall thickness, and station spacing can be determined.

It will be found that a system designed according to these principles, but without regard for the requirements of mechanical strength of the pipe, will result in a layout calling for pipe diameter, pipe-wall thickness, and station working pressure considerably at variance with established practicability. It is therefore necessary to base such computations not merely upon hydraulic considerations, but the question of sufficient wall thickness to insure mechanical strength must be introduced in a manner so as to reflect requirements which, in the past, have been found satisfactory in fulfilling these conditions.

Illustration by means of an actual example reveals the very striking fact that a difference of one commercial size in the pipe diameter of such a system may affect the total yearly cost by sums of such magnitude that the carrying out of such basic calculations is amply justified.



IN ITS initial conception, the oil-pipe-line design problem is usually stated in the form of providing transportation of a given quantity Q barrels from point A to destination B. When confronted with this problem, it has long been the endeavor of pipe-line engineers to solve the fundamental question as to whether the proposed system should be laid out on the basis of relatively small diameter pipe calling for the installation of many relay stations employing high working pressure or whether the system should be designed with larger pipe and thus reduce the number of pumpings. It is of course easily seen that, if the first plan can be followed, the total investment in the system is likely to be much less than if larger diameter pipe and fewer stations had been chosen. But it also follows that operating charges, such as successive pumping costs, will have the tendency to offset the saving created by the lowered fixed or capital charges of the lower-priced small-diameter pipe.

As in many other engineering problems, there is a middle ground where fixed or capital charges, which are a function of the magnitude of the investment, bear such a relationship to the operating expenses as to make the total yearly cost of the entire plant (i.e., the sum of all capital charges and operating expenses) a minimum.

How serious the results of disregarding these fundamental tenets of sound engineering design may become is clearly demonstrated by the experiences of one company which was confronted by electric power bills representing 20 per cent of its line operating revenue. When face to face with such a fact, checking over of equipment efficiencies is of little avail, for the causes lie much deeper. There is naturally an economic limit to the rate of operation for a line of given diameter, and if these boundaries are disregarded, the effect will make itself felt by inordinately high operating costs. On the other hand, a line diameter so large as to be out of all proportion to the quantity of oil to be transported gives rise to fixed or capital charges which will be severely felt on the balance sheet. The numerical solution of this problem should therefore be of greatest interest to the oil-pipe-line transportation industry.

With carriers of energy in its various forms, be they electric-transmission lines or pipe-line systems handling gas, water, or crude petroleum, the annual cost to be charged against the system may be classified under two headings:

(1) Fixed, or capital, charges proportional to the investment
(2) Operating costs, depending on number and size of pump stations.

If we designate the fixed, or capital, charges by Y and the operating expenses by X, it has already been indicated that a

[1] Assistant Chief Engineer, Texas Pipe Line Company. Mr. Wolf was graduated from the Grossherzogliche Oberrealschule, Pforzheim, Baden; Bucknell University, Lewisburg, Pa., 1912. From 1912 to 1922 he was engineer of the southern group of pipe lines, Texas Pipe Line Co.; 1922 to 1928, Superintendent of Stations; 1928 to date, in his present position.

Presented at the National Petroleum Meeting, Tulsa, Okla., October 6 to 8, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

change in one of these quantities will affect the other in opposite direction. The most elementary reasoning leads one to expect high operating costs on a pipe-line system of comparatively small diameter and many relay stations which are operating at excessive working pressures. Since the greatest part of the investment of a pipe-line transportation system is represented by the pipe in the ground, such a system as the one just mentioned would naturally have lower fixed charges than one laid out on the basis of larger diameter pipe and fewer stations.

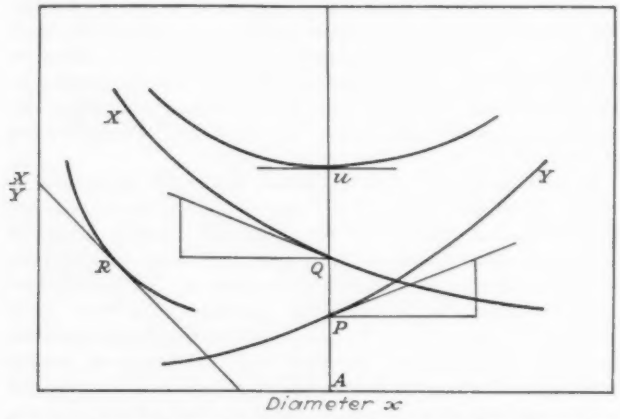


FIG. 1 CURVES SHOWING EFFECT OF CHANGE OF PIPE DIAMETER ON FIXED CHARGES Y AND OPERATING EXPENSES X

If we denote the total yearly cost of the system by u, it follows from the foregoing that[2]

$$u = X + Y \quad \ldots\ldots [1]$$

and it is the nature of our present problem to determine the conditions under which u will be a minimum. Designating the inside diameter of the pipe by x, and differentiating Equation [1], we obtain

$$\frac{du}{dx} = \frac{dX}{dx} + \frac{dY}{dx} \quad \ldots\ldots [2]$$

From the differential calculus we know this expression to be a minimum if $\frac{du}{dx} = 0$, and $\frac{d^2u}{dx^2}$ is positive in sign.

Hence

$$\frac{dX}{dx} = -\frac{dY}{dx} \quad \ldots\ldots [3]$$

and a maximum or minimum value of u will be found for the value of x, for which the slopes of X and Y are numerically the same, but opposite in direction. This condition will be fulfilled at some point A in the diagram shown as Fig. 1. This point A may be determined by plotting X and Y and locating the minimum point for u by trial and error. This point must fulfil the conditions of Equation [3] for the tangents at P and Q.

It also follows from Equation [3] that

$$\frac{dY}{dX} = -1 \quad \ldots\ldots [4]$$

which means that if we plot Y against X, the values of X and Y which will produce a minimum for u will be at point R, where the slope of the tangent is 135 deg., or where it is 45 deg. with the horizontal.[3]

[2] W. F. Durand, "Hydraulics of Pipe Lines," pp. 226–267.
[3] W. F. Durand, "Hydraulics of Pipe Lines."

In the equation $u = X + Y$

X = line maintenance plus station operation (fuel, lubrication, labor, maintenance, and supplies)
Y = annual amount of interest plus depreciation and taxes on all items of investment.

The application of these general equations to a definite pipe-line design problem makes it necessary that all terms entering into them be expressed as functions of the known quantities, such as length of line, permissible unit stress on steel in pipe, amount to be transported, physical characteristics of the oil, and the initial and terminal elevations of the line in question.

Most pipe-line systems of more than ordinary length require the operation of a number of pump stations in series. The following analysis is based on the assumption, easily carried out in practice, that the total power requirement of the entire system is equally divided among the several stations (Fig. 2). The pipe line is also assumed to have the uniform inside diameter of x inches throughout the entire length of the system.

Denoting:

L = length of line (miles)
Q = quantity to be pumped (bbl. per hr.)
η = kinematic viscosity of oil (c.g.s.)
s = specific gravity of oil

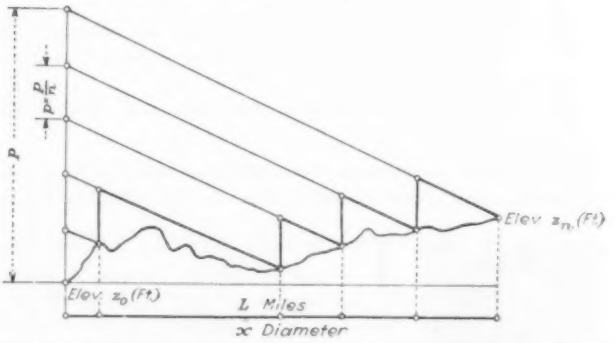


FIG. 2 PUMP-STATION SPACING ON PIPE LINE FOR EQUAL LOADS

S = permissible unit stress on steel in pipe (lb. per sq. in.)
n = number of stations on system
p = station gage pressure (lb. per sq. in.)
P = total pressure head (lb. per sq. in.)
t = thickness of pipe wall (in.)
x = inside diameter of pipe (in.)
N = operating life of system (years)
R = interest rate
T = rate of taxes and insurance
Δ = depreciation rate
σ = salvage value of system (decimal fraction).

SECTION I

FIXED CHARGES Y

The annual fixed charges of the system are equal to:

$$Y = [\text{first cost of line} + \text{first cost of stations}][(1 - \sigma)\Delta + R + T] + \text{value of oil in line } [R + T]$$

The depreciation rate Δ is based on the theory that the investor is entitled to the return of his capital during the operating life of the property. If the depreciation reserve is productively invested from year to year at the interest rate R and compounded annually, the depreciation rate

$$\Delta = \frac{R}{(1+R)^N - 1}^{4} \quad \ldots\ldots\ldots\ldots\ldots [5]$$

$$N = \frac{\log\left(\frac{R}{\Delta} + 1\right)}{\log\,(1+R)} \quad \ldots\ldots\ldots\ldots\ldots [6]$$

when applied to the total investment, will insure the return of the first cost of line and stations, less salvage, at the end of the operating period N.

The following salvage values are tentatively suggested for the line and stations:

SALVAGE VALUE, PER CENT OF FIRST COST[5]

Operating period	Line	Stations
5 years	25 per cent	25 per cent
10 years	15 per cent	15 per cent
15 years	10 per cent	10 per cent
20 years	.....	.....
30 years	.....	.....

According to the Barlow formula, the wall thickness of this pipe may be expressed by the following equation:

$$t = \frac{(x + 2t)p}{2S}$$

which reduces to

$$t = \frac{xp}{2(S-p)} \quad \ldots\ldots\ldots\ldots\ldots [7]$$

and the sectional area of the pipe wall

$$\text{Area} = (x + t)\,t\pi$$

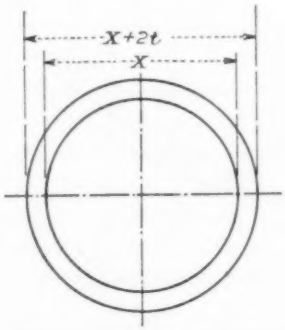


FIG. 3 PIPE-WALL SECTION

which reduces to

$$\text{Area} = \frac{x^2 p\pi}{2(S-p)}\left(1 + \frac{p}{2(S-p)}\right) \text{(square inches)}$$

If we assume the weight of steel at 0.2833 lb. per cu. in., the weight per mile of pipe may be written as follows:

$$\text{Weight per mile of pipe} = \frac{x^2 p\pi}{2(S-p)}\left(1 + \frac{p}{2(S-p)}\right) \times \frac{5280 \times 12 \times 0.2833}{2000} \text{(tons)} = \frac{14.1x^2 p}{S-p}\left(1 + \frac{p}{2(S-p)}\right) \text{(tons)}$$

which can be transformed into:

$$\text{Weight per mile of pipe} = 7.05x^2\left(\frac{S^2}{(S-p^2)} - 1\right) \text{(tons)} \quad [8]$$

Multiplying Equation [8] by the cost per ton of steel, we obtain

$$\text{Cost per mile of pipe} = 7.05x^2\left(\frac{S^2}{(S-p)^2} - 1\right) \times \text{cost per ton of steel}$$

$$\text{Cost per mile of pipe} = 7.05x^2\left(\frac{S^2}{\left(S - \frac{P}{n}\right)^2} - 1\right) \times \text{cost per ton of steel} \quad \ldots\ldots [9]$$

The average cost of finished steel pipe, delivered at Texas common points, on the basis of cost per ton, is shown in the diagram Fig. 4. When expressed as a function of the pipe diameter x, the cost per ton of fabricated pipe is given by the equation:

$$\text{Cost per ton of steel pipe} = \frac{100}{x^{0.133}} \text{(dollars)}$$

This value must of course be multiplied by a proper coefficient allowing for difference in freight rates between average Texas

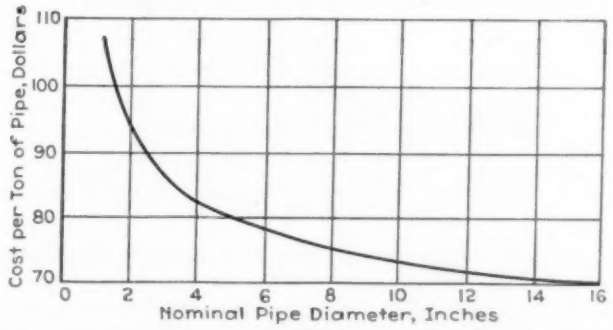


FIG. 4 AVERAGE PRICE PER TON OF STEEL PIPE AS A FUNCTION OF THE DIAMETER (TEXAS COMMON POINTS)

common-point shipments and those in force for the prospective location of the system under analysis. Abnormal basic costs of steel should also be incorporated in this coefficient.

Introducing this value in Equation [9], we obtain for the cost of steel in pipe, delivered, for a system of length L:

$$\text{Cost of pipe} = 705x^2\left(\frac{S^2}{\left(S - \frac{P}{n}\right)^2} - 1\right)\frac{L}{x^{0.133}} \text{(dollars)}$$

which may be written in the form:

$$\text{Cost of pipe} = 705x^{1.867}\left(\frac{S^2}{(S-p)^2} - 1\right) L \text{ (dollars)} \quad \ldots [10]$$

This expression establishes the relation between the cost of fabricated pipe and the strength of the steel for a given working pressure p. If the pipe is made of high-carbon steel containing 0.2 to 0.3 per cent carbon and electrically welded in the longitudinal seam, maximum unit fiber stresses S = 15,000 to 16,000 lb. per sq. in. and 100 per cent longitudinal joint efficiency may safely be employed. If, on the other hand, the skelp is made of 0.08 to 0.15 per cent carbon steel and the pipe is of lap-welded fabrication, the value of S should be reduced to the

[4] Goldman, "Financial Engineering."

[5] These percentages are to be applied to the whole investment. They are purposely kept low, since a certain portion of the investment is nonsalvageable. For pump stations this nonsalvageable portion in the investment is approximately 35 per cent and for pipe lines from 40 to 50 per cent of the whole investment.

neighborhood of from 10,000 to 12,000 lb. per sq. in., with corresponding deductions for the longitudinal joint efficiency. This formula therefore furnishes a ready means for comparing the cost of pipe when based on steels of different working stresses, assuming of course that the working pressure remains constant.

In the diagram, Fig. 5, it will be noticed that the actual costs per mile indicated for the various pipe sizes fall considerably above the curves for the smaller pipe diameters. This is accounted for by the reason that for the smaller sizes of pipe the wall thicknesses of standard "line pipe" are much greater than considerations based entirely on hydraulic pressure would warrant. This extra thickness is provided to insure the necessary mechanical strength for the pipe. Again, the working pressure rating for the pipe sizes below 6 in. is somewhat higher than the 750 lb. forming the basis for the set of curves shown in Fig. 5.

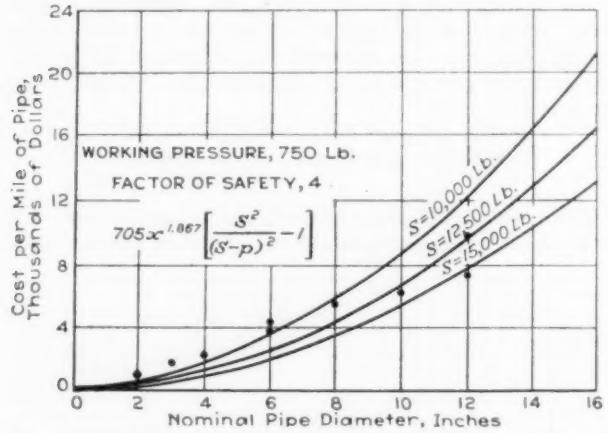


FIG. 5 COST PER MILE OF STEEL PIPE AS A FUNCTION OF THE PERMISSIBLE FIBER STRESS

The cost of laying the line varies, of course, with the physical characteristics and topography of the terrain traversed by the line. Wide variation in the construction costs for a given size of line are to be expected, as they are a function not only of the factors mentioned above, but also of the efficiency of the construction organization and of the type of construction, i.e., whether gas-, electrically welded, or screw-connected. The following formula gives results representing fair average results. It can, however, be so modified as to represent such special conditions as may, in the judgment of the engineer, be warranted. It is naturally supposed that the general features of the terrain traversed by a pipe-line project under analysis are sufficiently known to permit an intelligent application of such information as may be obtained from past construction cost records.

$$\left.\begin{array}{l}\text{Pipe-line construction:}\\ \text{Cost per mile of line}\\ \text{(includes cost of right-}\\ \text{of-way .....}\end{array}\right\} = \left\{\begin{array}{c}120x + 44.5x^2 \text{ (high)}\\ 100x + 36x^2 \text{ (average)}\\ 50x + 32.5x^2 \text{ (low)}\end{array}\right\}$$

(dollars).....[11]

The total line investment can now be expressed by the following equation:

$$\text{Total cost of line} = \left\{705x^{1.867}\left[\frac{S^2}{(S-p)^2}-1\right] + 100x + 36x^2\right\} L \text{ (dollars)}.....[12]$$

It follows from the preceding discussion that the amount of steel in the line is regarded as a direct function of the unit maximum fiber stress permissible on the steel under consideration. An economic design study based on this assumption will be found to produce results calling for such thin pipe-wall sections that an application of this formula without qualifying limitations is impossible. It is of course obvious that the pipe must have sufficient wall thickness to satisfy all requirements for mechanical strength, aside from the stresses brought to bear upon it by the internal fluid pressure.

The factors influencing the choice of a minimum wall thickness for a given size of pipe are enumerated by Professor Durand in his "Hydraulics of Pipe Lines," and according to his statement the pipe-wall thickness must be sufficient to take care of:

1 The maximum static or steady-condition pressure to which the pipe is likely to be subjected in operation
2 Any excess pressure due to shock or water hammer to which the pipe may be exposed
3 Collapsing pressure due to a reduction of pressure on the inside to less than atmospheric pressure
4 Stiffness, rigidity, and strength to meet such bending stresses as may be set up due to the action of the pipe as a beam
5 Any reasonable special stresses to which the pipe may be subjected as a result of expansion and contraction under temperature changes

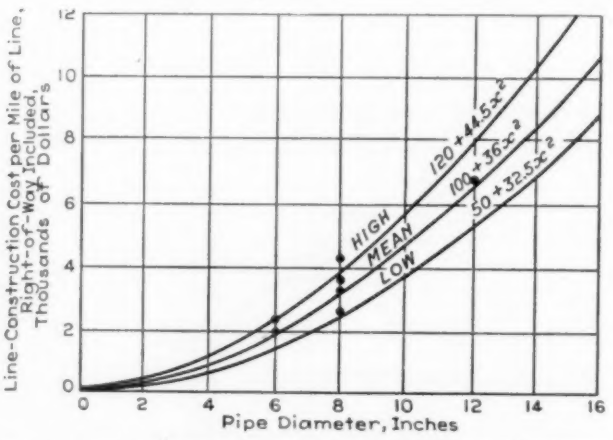


FIG. 6 LINE-CONSTRUCTION COST AS A FUNCTION OF THE DIAMETER

6 Special stress due to distortion of the cross-section of pipe from true circular form, or failure to realize this form as in lap-riveted pipe
7 The usual variations to be expected in the strength of the plates resulting from the accidents of manufacture
8 Corrosion and wear, in order that the pipe may have a lifetime of reasonable length and without too rapid decline of the factor of safety.

This minimum pipe-wall thickness is, naturally, a function of the pipe diameter, based largely upon previous satisfactory experience for the fulfilment of all the conditions mentioned. The years of experience with pipe lines of such diameters as come within the scope of oil-pipe-line systems suggest a minimum wall thickness expressed by the following equation:

$$\text{Minimum pipe-wall thickness} = t' = 0.17 + \frac{x}{100} \text{ (inches)}. [13]$$

Denoting:

t' = minimum pipe-wall thickness
p' = safe working pressure for unit stress S

we have, according to Equation [7]:

$$t' = \frac{p'x}{2(S - p')}$$

and substituting Equation [13], we obtain:

$$p' = \frac{S(17 + x)}{51x + 17} \text{ (Pounds per square inch)} \ldots\ldots [14]$$

which represents the safe working pressure for the pipe as based on fiber stress S and minimum wall thickness t'. The pipe-section area has previously been shown to be

$$\frac{p'x^2\pi}{2(S - p')}\left[1 + \frac{p'}{2(S - p')}\right]$$

and substituting the expression for p' in this equation, we obtain:

$$\text{Minimum pipe-section area} = \frac{(101x^2 + 1734x + 289)\pi}{10{,}000} \text{ (Square inches)} \ldots\ldots [15]$$

and in the following discussion the value of the working pressure p must be so chosen as to fulfil the conditions:

$$p \geqq p' = \frac{S(17 + x)}{51x + 17}$$

and

$$\frac{px^2\pi}{2(S - p)}\left[1 + \frac{p}{2(S - p)}\right] \geqq \frac{(101x^2 + 1734x + 289)\pi}{10{,}000} \text{ (Square inches)} \ldots [16]$$

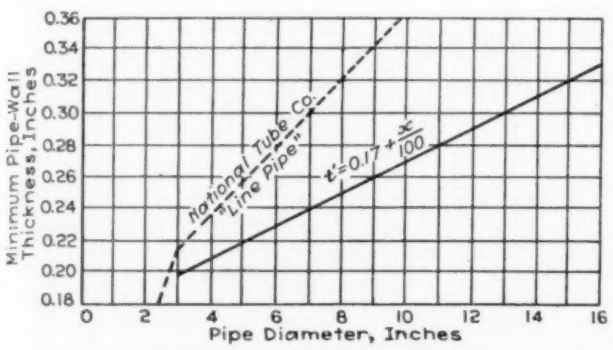


FIG. 7 MINIMUM PIPE-WALL THICKNESS

For a given size line the minimum cost of the pipe should therefore be not less than

$$\frac{L(101x^2 + 1734x + 289)\pi \times 5280 \times 12 \times 0.2833}{10{,}000 \times 2000} \times \text{cost per ton of steel}$$

$$\text{Minimum cost of pipe} = \frac{0.282L(101x^2 + 1734x + 289)}{x^{0.133}} \text{ (dollars)} \ldots [17]$$

and the total minimum line investment is represented by

$$\text{Minimum line investment} = \left[\frac{0.282(101x^2 + 1734x + 289)}{x^{0.133}} + 100x + 36x^2\right] L \text{ (dollars)} \ldots [18]$$

WORKING PRESSURES FOR MINIMUM SECTION AREA STEEL PIPE

Nominal diameter, in.	x	$\frac{17 + x}{51x + 17}$	S = 10,000 lb. (lb.)	S = 12,500 lb. (lb.)	S = 15,000 lb. (lb.)
2.....	2.07	0.1550	1550	1938	2327
3.....	3.07	0.1154	1154	1443	1732
4.....	4.03	0.0945	945	1181	1418
6.....	6.07	0.0705	705	880	1057
8.....	7.98	0.0590	590	738	884
8.....	8.25	0.0590	590	738	885
10.....	10.02	0.0512	512	639	767
12.....	12.00	0.0461	461	576	714
12.....	12.144	0.0458	458	572	686
20.....	19.34	0.0369	369	461	554

$$p' = \frac{S(17 + x)}{51x + 17}$$

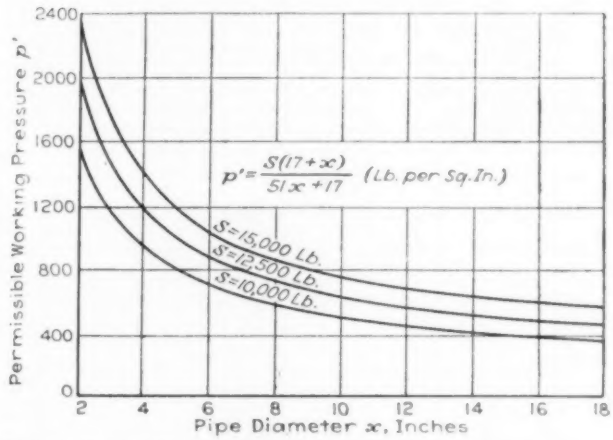


FIG. 8 PERMISSIBLE WORKING PRESSURE FOR MINIMUM WALL-THICKNESS PIPE

The equation for the fixed charges on the line investment may now be written:

$$\text{Fixed charges on line investment} = \left[705x^{1.667}\left(\frac{S^2}{(S - p)^2} - 1\right) + 100x + 36x^2\right]\left[(1 - \sigma)\Delta + R + T\right] L \text{ (dollars)} \ldots [19]$$

in which σ is the salvage value of the line corresponding to the operating life N under consideration. σ is expressed as a decimal fraction. The value of Equation [19] should never be less than

$$\left[\frac{0.282\,L\,(101x^2 + 1734x + 289)}{x^{0.133}} + (100x + 36x^2)\,L\right]\left[(1 - \sigma)\Delta + R + T\right] \text{ (dollars)} \ldots [20]$$

which represents the cost of the line as based on the minimum pipe-wall section which is required to satisfy the conditions enumerated.

OIL-PIPE-LINE DESIGN

The expression $P/n = p$ represents the station working pressure (see Fig. 2), which can be derived as a function of the line diameter x, the length of the system L, and the physical characteristics of the oil η and s. Inasmuch as practically all pipe-line systems handling oils of ordinary viscosities are operating under conditions of turbulent flow, i.e., $Q/x\eta < 93$, only that regime of flow will be considered in the following analysis. Exceptions are the lines handling highly viscous California and Mexican crudes which require heating before being pumped into the line.

The friction head, in pounds per square inch, is given by:

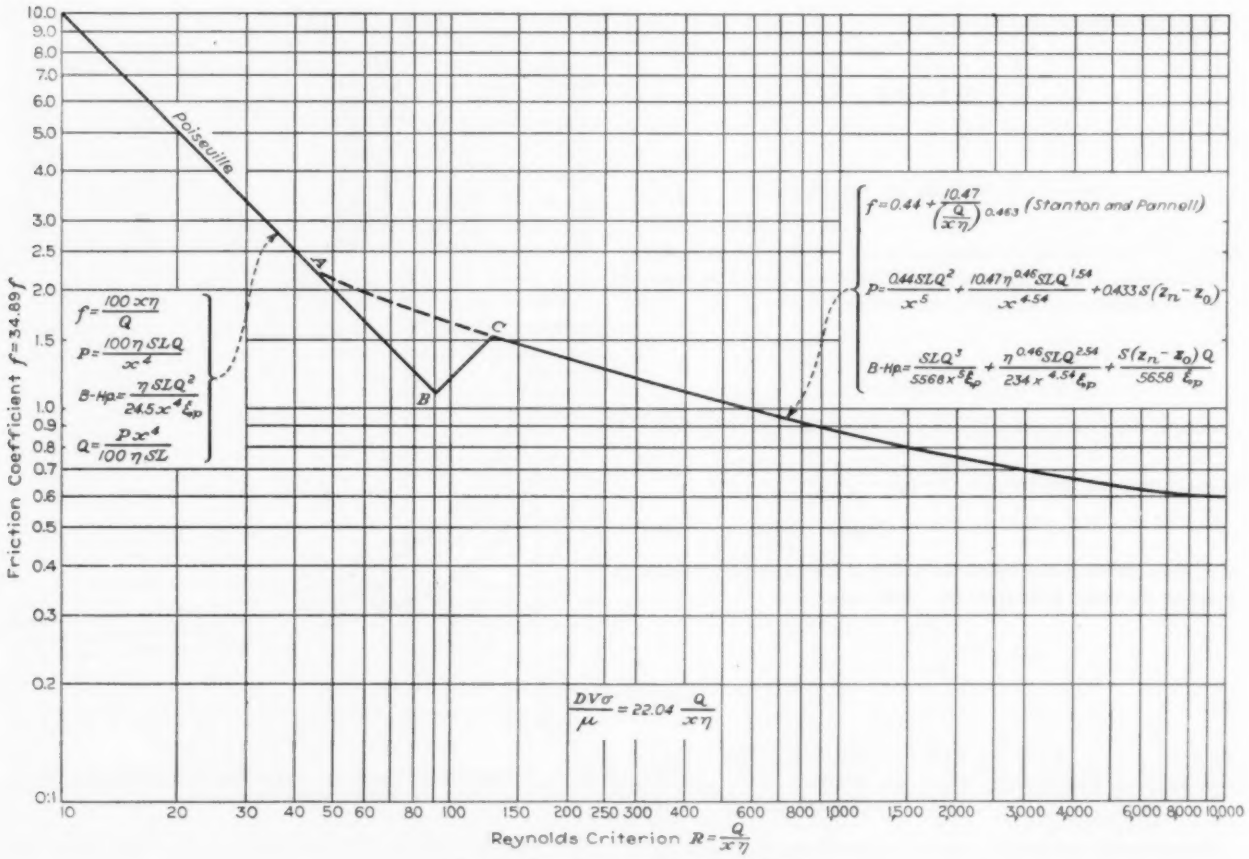


FIG. 9 STANTON AND PANNELL CURVE

$$P = \frac{fsLQ^2}{x^5} \quad \ldots\ldots [21]$$

in which

P = friction head (lb. per sq. in.)
s = specific gravity of the oil
L = length of line (miles)
Q = rate of flow (bbl. per hour)
x = inside diameter of pipe (in.)
f = friction coefficient.

The friction coefficent f has been found to be a function of

$$f = \Phi\left(\frac{Q}{x\eta}\right) = \Phi\left(\frac{sQ}{x\mu}\right) \quad \ldots\ldots [22]$$

μ = absolute viscosity (poises)
η = kinematic viscosity = μ/s

This function was evaluated by Stanton and Pannell at the National Physical Laboratory, London.[6]

The turbulent-flow region of the curve in Fig. 9 may be expressed by the equation:

$$f = 0.44 + \frac{10.47}{\left(\frac{Q}{x\eta}\right)^{0.463}} \quad \ldots\ldots [23]$$

and by substituting in the formula for P, we obtain:

$$P = \frac{0.44sLQ^2}{x^5} + \frac{10.47\nu^{0.46}sLQ^{1.54}}{x^{4.54}} + 0.433s(z_n - z_o)$$

(lb. per sq. in.) .... [24]

[6] Stanton and Pannell, Philosophical Transactions of the Royal Society, A, vol. 213.

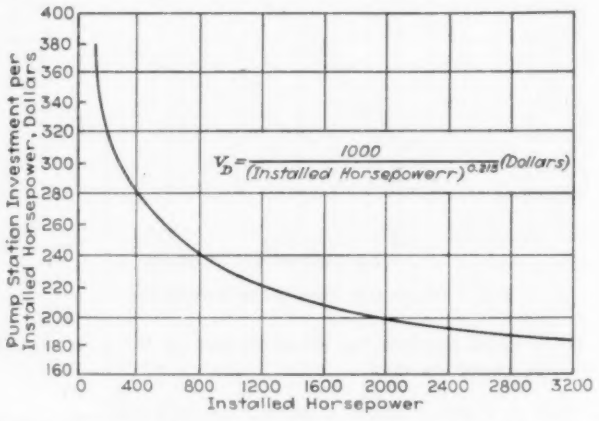


FIG. 10 STATION INVESTMENT PER INSTALLED HORSEPOWER (DOLLARS)

in which

z_n = elevation of terminal point of the pipe line (feet)
z_o = elevation of initial point of the pipe line (feet)

and $0.433s(z_n - z_o)$ represents the static head on the system, expressed in pounds per square inch.

The hydraulic horsepower of a pump may be shown to be:

$$\text{Hydraulic horsepower} = PQ/2450$$

and if the pump efficiency is given by E_p, the brake horsepower necessary for the operation of the pump is:

$$\text{Brake horsepower} = PQ/2450E_p$$

Introducing Equation [24] in this expression, we get

$$\text{Brake horsepower} = \frac{sLQ^3}{5568x^5E_p} + \frac{\eta^{0.46}sLQ^{2.54}}{234x^{4.54}\,E_p} + \frac{s(z_n - z_o)Q}{5658E_p} \quad \ldots\ldots [25]$$

It is to be noted that this represents the total horsepower required for pumping the quantity Q through the entire length of the system, and if the line is so designed that each station will carry an equal portion of the total load, the horsepower per station will be:

$$\text{Brake horsepower per station} = \frac{s}{nE_p}\left(\frac{LQ^3}{5568x^5} + \frac{\eta^{0.46}LQ^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)Q}{5658}\right) \ldots [26]$$

It is considered good practice to install a certain amount of extra pumping capacity for standby purposes, and if we assume this additional installation at 25 per cent of the required horsepower, the total installed capacity of the plant will be:

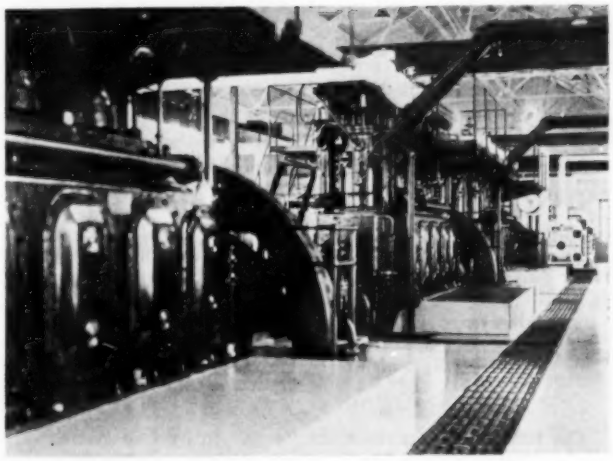


FIG. 13 WEST DALLAS DIESEL PUMP STATION

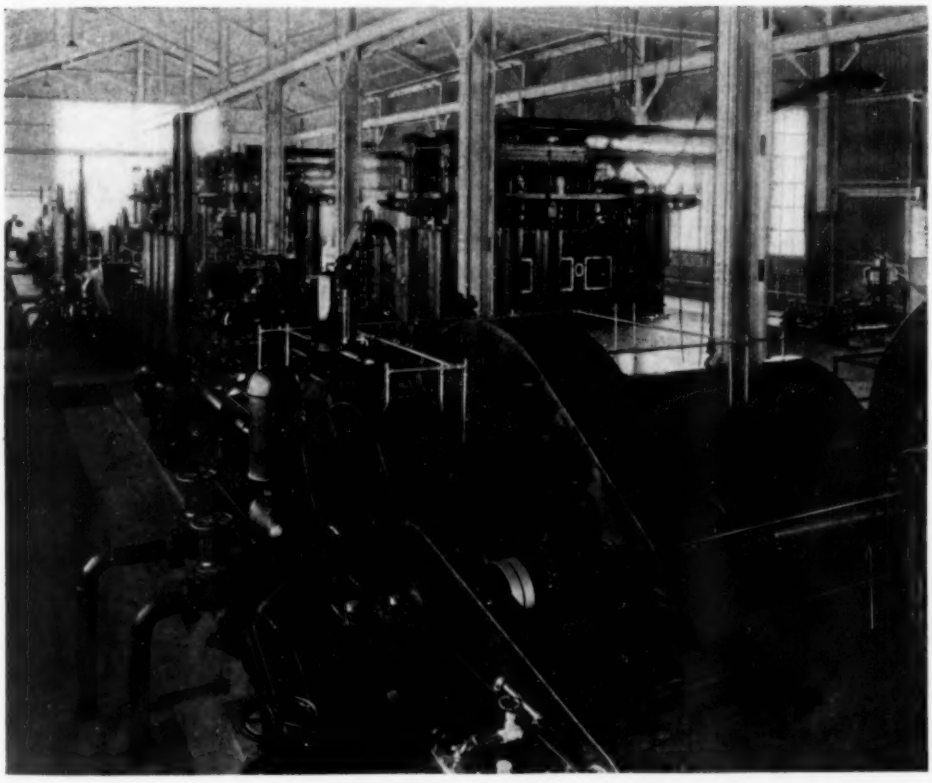


FIG. 12 JUNCTION DIESEL PUMP STATION



FIG. 11 EXTERIOR VIEW OF ROSANKY DIESEL PUMP STATION

$$\text{Installed horsepower per station} = \frac{1.25s}{nE_p}\left(\frac{LQ^3}{5568x^5} + \frac{\eta^{0.46}LQ^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)Q}{5658}\right) \ldots [27]$$

and if

V = cost per installed horsepower (dollars)

the total station investment for the entire system (n stations) will be:

$$\text{Cost of } n \text{ pump stations} = \frac{1.25sV}{E_p}\left(\frac{LQ^3}{5568x^5} + \frac{\eta^{0.46}LQ^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)Q}{5658}\right) \text{(dollars)} \ldots 28]$$

The unit cost V per installed horsepower depends upon the type of station; i.e., whether Diesel-driven, motor-operated reciprocating pumps, or centrifugal units. It is of course also a function of the general quality of the plant, the elaborateness of the design, and the efficiency of the construction organization. Wide fluctuations of unit cost are naturally to be expected under these conditions, and the following data are representative of average conditions only, to be multiplied by such coefficients as will allow for such deviation from the average as may, in the judgment of the designing engineer, be warranted. An increase or decrease of 15 per cent from the following data shown should be sufficient to delineate the range normally encountered. The unit cost per installed horsepower may be assumed as follows:

1 *Diesel Stations.* The following unit-cost figures cited include all of the main pumping equipment, auxiliaries, piping, cooling systems, and buildings. Inasmuch as the amount of working tankage provided for each station varies somewhat

with the policies of the different companies, this item will be considered separately. The general features of construction may be seen from the views in Figs. 11, 12, and 13. The cost per horsepower installed varies with the size of the installation, and may be expressed as a function of the installed horsepower. It is assumed, however, that the sizes of the individual units making up the installation are commensurate with the general capacity of the plant.

$$\text{Cost per installed horsepower} = V_D = \frac{1000}{\left(\text{Installed horsepower per station}\right)^{0.215}}$$

$$\text{(dollars)} = \frac{1000}{\left[\frac{1.25s}{nE_p}\left(\frac{LQ^2}{5568x^5} + \frac{\eta^{0.46}L^2Q^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)Q}{5658}\right)\right]^{0.215}} \text{ (dollars)} \quad [29]$$

The total station investment for the entire line system of n stations is therefore given by:

$$\text{Total station investment } n \text{ stations} = 1000n^{0.215}\left[\frac{1.25s}{E_p}\left(\frac{LQ^2}{5568x^5} + \frac{\eta^{0.46}LQ^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)Q}{5658}\right)\right]^{0.785} \text{(dollars)} \quad [30]$$

2 *Motor-Driven Reciprocating Station.* For motor-driven reciprocating stations the investment per installed horsepower is approximately one-half of that required for Diesel stations. Hence:

$$V_{MR} = \frac{500}{(\text{installed horsepower})^{0.215}} \text{ (dollars)}$$

and the total station investment for the entire line system of n stations is therefore given by:

$$\text{Total pump station investment } n \text{ stations} = 500n^{0.215}\left[\frac{1.25s}{E_p}\left(\frac{LQ^2}{5568x^5} + \frac{\eta^{0.46}LQ^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)Q}{5658}\right)\right]^{0.785} \text{(dollars)} \quad [31]$$

3 *Motor-Driven Centrifugal Station.* For motor-driven centrifugal stations the investment per installed horsepower is approximately one-fourth of that required for Diesel stations. Hence:

$$V_C = \frac{250}{(\text{installed horsepower})^{0.215}} \text{ (dollars)}$$

and the total station investment for the entire line system of n stations is therefore given by:

$$\text{Total station investment } n \text{ stations} = 250n^{0.215}\left[\frac{1.25s}{E_p}\left(\frac{LQ^2}{5568x^5} + \frac{\eta^{0.46}LQ^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)\,Q}{5658}\right)\right]^{0.785} \text{(dollars)} \quad [32]$$

Tankage. On long pipe-line systems made up of a number of pump stations operating in series, it is sufficient to provide the stations with single tanks only which "float" on the line, and thus absorb any difference in the rate of pumping which may exist between successive stations. "Check" stations are provided at certain intervals for an accurate gage on the oil stream passing through the system, and these stations are equipped with two or more tanks. The "floating" tankage erected at each station varies from 50 to 100 per cent of the daily oil movement passing through the system. If elasticity of operation and security against interruptions of service are of vital concern, the amount of tankage thus provided should be as large as possible. Naturally this is governed more or less by the general policies of the company making the installation. If we designate the size of each tank as a decimal fraction K of the daily line capacity, we obtain:

$$\text{Size of tank} = 24\,KQ \quad [33]$$

and

$$\text{Cost per tank} = 24\,KQ \times C \quad [34]$$

in which C = unit cost per barrel of capacity $24\,KQ$, and if we decide to install a total of $n + v$ tanks on the system, the total cost for tankage will be:

$$\text{Cost of working tankage} = 24\,KQ(n + v) \times \text{cost per bbl. of capacity} \quad [35]$$

Fixed Charges on Pump Station Investment (n Stations)

The equation for the fixed charges on the station investment may now be written.

1 *Diesel Station:*

$$\left\{1000n^{0.215}\left[\frac{1.25s}{E_p}\left(\frac{LQ^2}{5568x^5} + \frac{\eta^{0.46}LQ^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)Q}{5658}\right)\right]^{0.785} + 24KQ\,(n + v)C\right\}\left[(1 - \sigma)\Delta + R + T\right] \text{ (dollars)} \quad [36]$$

2 *Motor-Driven Reciprocating Station:*

$$\left\{500n^{0.215}\left[\frac{1.25s}{E_p}\left(\frac{LQ^2}{5568x^5} + \frac{\eta^{0.46}LQ^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)Q}{5658}\right)\right]^{0.785} + 24\,KQ(n + v)C\right\}\left[(1 - \sigma)\Delta + R + T\right] \text{ (dollars)} \quad [37]$$

3 *Motor-Driven Centrifugal Station:*

$$\left\{250n^{0.215}\left[\frac{1.25s}{E_p}\left(\frac{LQ^2}{5568x^5} + \frac{\eta^{0.46}LQ^{2.54}}{234x^{4.54}} + \frac{(z_n - z_o)Q}{5658}\right)\right]^{0.785} + 24KQ(n + v)C\right\}\left[(1 - \sigma)\Delta + R + T\right] \text{ (dollars)} \quad [38]$$

For any given problem the following terms are constant, and denoting:

$$a = 0.44sLQ^2$$

$$b = 10.47\eta^{.046}sLQ^{1.54}$$

$$c = 0.433s(z_n - z_o)$$

$$\alpha = \frac{sLQ^2}{5568E_p}$$

$$\beta = \frac{\eta^{0.46}sLQ^{2.54}}{234E_p}$$

$$\gamma = \frac{s(z_n - z_o)Q}{5658E_p}$$

the Equations [36], [37], and [38] may be written in simpler form, and the total annual fixed charge for the line and pump station investment of the system is given by:

$$\left[\left\{705x^{1.867}\left[\frac{S^2}{(S - p)^2} - 1\right] + 100x + 36x^2\right\}L + 1000n^{0.215}\left[1.25\left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)\right]^{0.785} + 24KQ(n + v)C\right]\left[(1 - \sigma)\Delta + R + T\right] \text{ (dollars)} \quad [39]$$

in which

$$p = \frac{P}{n} = \frac{a}{nx^5} + \frac{b}{nx^{4.54}} + \frac{c}{n} \quad \ldots\ldots\ldots\ldots [40]$$

If the value of the crude oil in the line is assumed at φ dollars per barrel, the fixed charges representing interest and taxes on this investment are given by:

Fixed charges on oil in line $= 5.16\, x^2 \varphi L(R + T)$ (dollars). [41]

and the total fixed charges of the entire system:

$$Y = \left[\left\{705x^{1.867}\left[\frac{S^2}{\left(S - \frac{a}{nx^5} - \frac{b}{nx^{4.54}} - \frac{c}{n}\right)^2} - 1\right] + 100x + 36x^2\right\}L + 1000n^{0.215}\left[1.25\left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)\right]^{0.785} + 24KQ(n + r)C\right]\left[(1 - \sigma)\Delta + R + T\right] + 5.16x^2\varphi L\,(R + T) \text{ (dollars)}$$

$\ldots\ldots\ldots [42]$

Equation [42] represents the total fixed charges on a system based on Diesel-pump station installations. If either motor-driven reciprocating or centrifugal stations are under consideration, Equations [37] or [38], as the case may be, must be inserted in Equation [42]. It should also be remembered in connection with Equation [42] that its component representing the line investment should never be less than:

$$\frac{0.282L(101x^2 + 1734x + 289)}{x^{0.132}} + (100x + 36x^2)L \text{ (dollars)}. [18]$$

for the reasons mentioned.

SECTION II

Operating Expenses X

The operating expenses of a pipe-line system may be divided into:

(1) *Line Maintenance and Repairs*, which may be expressed by:

Annual cost of line maintenance and repair $= (50 + 1.5x)L$ (dollars)$\ldots\ldots\ldots [43]$

(2) *Station Operation*, i.e., (*a*) labor, (*b*) fuel, (*c*) lubrication, (*d*) maintenance and supplies, and in the case of motor-operated stations electrical energy.

(*a*) *Labor.* As to Diesel stations: The station attendance cost is naturally a function of the size of the station. It is further dependent upon the size of the individual units making up the total installation. A 1000-hp. station made up of ten 100-hp. units requires more operating labor than a station of the same size made up of two 500-hp. units. The following data are therefore based on the assumption that the individual unit capacities are commensurate with the total capacity of the station. If we express the attendance cost as a function of the installed horsepower, we obtain for a Diesel station:

Attendance cost per installed horsepower per year (Diesel engines), one station only $= \dfrac{2062}{(\text{installed horsepower})^{0.725}}$ (dollars)

$$= \frac{2062}{\left[\frac{1.25}{n}\left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)\right]^{0.725}} \text{ (dollars)}\ldots\ldots [44]$$

Hence the total attendance cost for n pump stations of the system is given by:

Total annual attendance cost n Diesel stations

$$= 1470n^{0.725}\left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)^{0.275} \text{ (dollars)}\ldots\ldots [45]$$

In the course of this analysis it will be assumed that the station attendance cost will remain the same whether the system is operated at 100 per cent "use factor" or not. This may not be strictly true when the system is operated at very low "use" or "load" factors, but it will not change the result of the analysis to any noticeable degree. It is further assumed that all of the pumping equipment will be operated at full load at all times, and that reductions in the average daily capacity of the system are brought about through reduction of the hours of pumping. In actual pipe-line operation practice this procedure is not always followed, it being more often the custom to reduce the load on the system through reduction of the working pressure

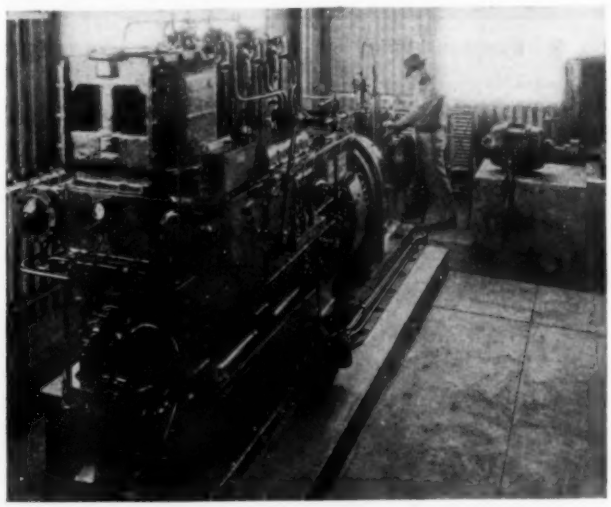


Fig. 14 Auxiliary Engine Room at Junction Diesel Pump Station



Fig. 15 Pump-Station Manifold at Heyworth Station

and, consequently, the average hourly rate of flow. Under some conditions it may even be found advantageous to "bypass" some of the stations altogether and thus obtain the reduction



FIG. 16 EXTERIOR VIEW OF FREDERICKSBURG CENTRIFUGAL PUMP STATION

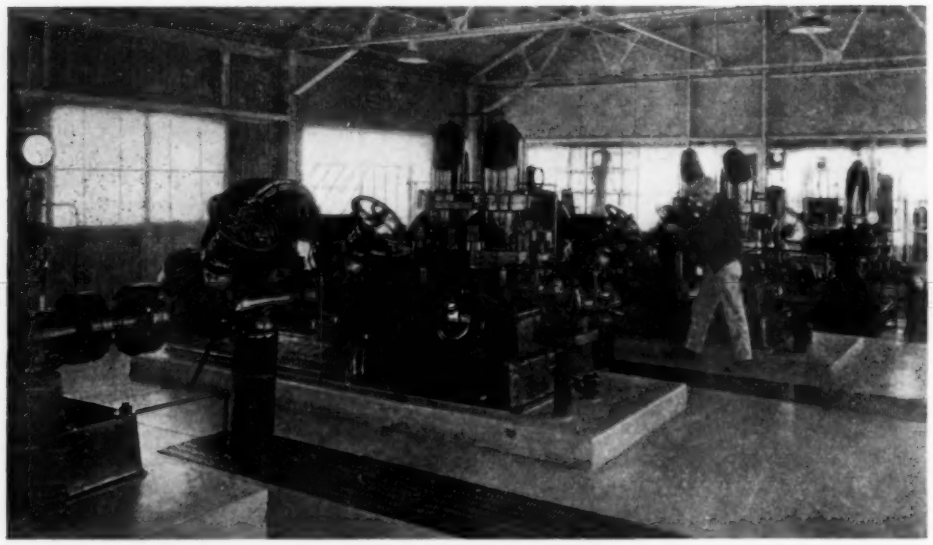


FIG. 17 CRANE CENTRIFUGAL PUMP STATION

in flow through lengthening the pumping distance between stations. In an investigation of this sort it is of course impossible to introduce all of these contingencies in a single mathematical equation, and the previously made assumption will therefore be used as the basis for operating costs at use factors less than 100 per cent.

As to motor-driven reciprocating stations: The attendance cost of a motor-operated reciprocating pump station is somewhat less than that required for a Diesel station of like capacity. If expressed on the basis of installed horsepower, the yearly labor cost per horsepower is given by the following equation:

Yearly attendance cost per installed horsepower (one station)

$$= \frac{4445}{(\text{installed horsepower})^{0.935}} \text{ (dollars)}$$

$$= \frac{4445}{\left[\frac{1.25}{n}\left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)\right]^{0.935}} \text{ (dollars)} \quad \ldots [46]$$

and the total attendance cost for the n stations of the system is:

Yearly total attendance cost n motor-reciprocating stations

$$= 4510n^{0.935}\left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)^{0.065} \text{ (dollars)} \quad \ldots [47]$$

As to motor-driven centrifugal pumps: The chief argument advanced in favor of the centrifugal-pump installation lies in its low first cost and small labor expense. When coupled with an advantageous power rate, the effect of its slightly lower efficiency may be offset so as to represent a very desirable installation from an economic point of view. As a function of the installed horsepower, the labor cost per horsepower per year is given by the equation:

Yearly attendance cost per installed horsepower (one station)

$$= \frac{6000}{(\text{installed horsepower})} \text{ (dollars)}$$

$$= \frac{6000}{\frac{1.25}{n}\left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)} \text{ (dollars)} \quad \ldots [48]$$

Hence the total attendance cost for the system of n pump stations is equal to:

Total yearly attendance cost (n centrifugal stations)

$$= 6000\ n \text{ (dollars)} \quad \ldots [49]$$

(*b*) *Fuel* (*Electrical Energy*). As to Diesel Stations:

Denoting:

- φ = cost per barrel of fuel (dollars)
- h = number of hours per year engines are in operation
- e = specific fuel consumption of engines per brake horsepower hour (may be assumed at 0.45 lb. for Diesel engines of good make)
- s' = specific gravity of fuel.

The total annual fuel cost for operating the n stations of the system is equal to:

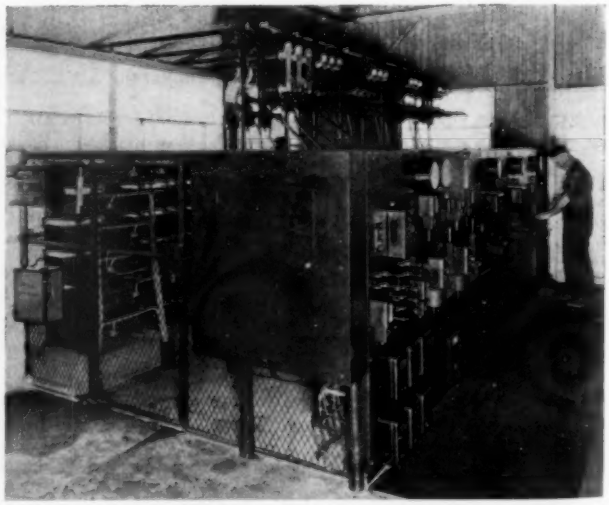


FIG. 18 SWITCHBOARD AT BROOKSHIRE CENTRIFUGAL PUMP STATION

$$\text{Annual cost of fuel} = \left(\frac{\alpha}{x^{\delta}} + \frac{\beta}{x^{4.54}} + \gamma\right)\frac{h\varphi e}{350\,s'} \text{ (dollars)} \quad [50]$$

As to motor-driven stations (centrifugal or reciprocating): Denoting:

φ'' = average energy cost per kw-hr. at load factor (per cent) $\frac{100\,h}{8760}$ (dollars).

The total annual cost of electrical energy for operating the n stations of the system is:

$$\text{Annual cost of electrical energy} = \left(\frac{\alpha}{x^{\delta}} + \frac{\beta}{x^{4.54}} + \gamma\right) \times 0.746\,h\varphi''$$

It is of course to be remembered that the pump efficiency E_p must be chosen in accordance with the type of station under consideration. For centrifugal stations of good design E_p ranges between 70 and 80 per cent, depending upon the size of the individual units. Values between 85 and 89 per cent may be assumed for reciprocating power pumps. Taking, for instance, an assumed energy rate of 1 per cent per kw-hr. at 100 per cent use factor, it will be obvious that the average cost per kilowatt-hour will be greater than 1 cent at use factors lower than 100 per cent. There is, unfortunately, no uniformity

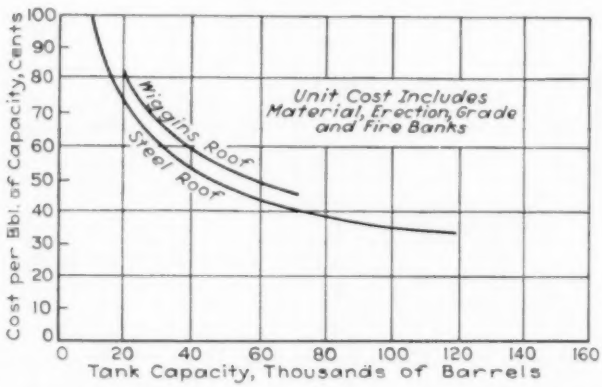


FIG. 19 COST OF STEEL TANKAGE PER BARREL OF CAPACITY

of form nor rate at which electrical energy is being offered by the various power companies. However, the following curve will serve as a typical example for the average cost per kilowatt-hour at different use factors, where the 100 per cent average is 1 cent per kw-hr. It is also appreciated that this rate will vary somewhat with the "demand" put upon the power company, and the following data are therefore offered for illustrative purposes only.

For a load or use factor range between 30 and 100 per cent, such a representative rate may be expressed by the following equation:

$$\varphi'' = \text{average cost per kw-hr.} = \frac{0.048}{(\text{use factor})^{0.34}} \text{ (dollars)}$$

in which the use factor is equal to $100h/8760$; hence

$$\varphi'' = \text{average cost per kw-hr.} = \frac{0.22}{h^{0.34}} \text{ (dollars)} \quad [51]$$

and the total annual energy cost for the system of n stations is:

$$\text{Total annual energy cost } (n \text{ stations}) = 0.164h^{0.66}\left[\frac{\alpha}{x^{\delta}} + \frac{\beta}{x^{4.54}} + \gamma\right] \text{ (dollars)} \quad [52]$$

Equation [52] is of course true only for this particular energy rate and for use factors between 30 and 100 per cent.

If the power rate is materially different from that cited, the actual values of φ'' must be used in accordance with the contract offered.

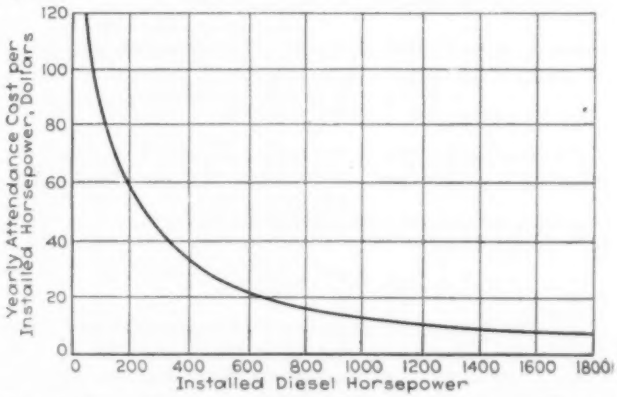


FIG. 20 PUMP STATION ATTENDANCE COST PER INSTALLED HORSEPOWER PER YEAR

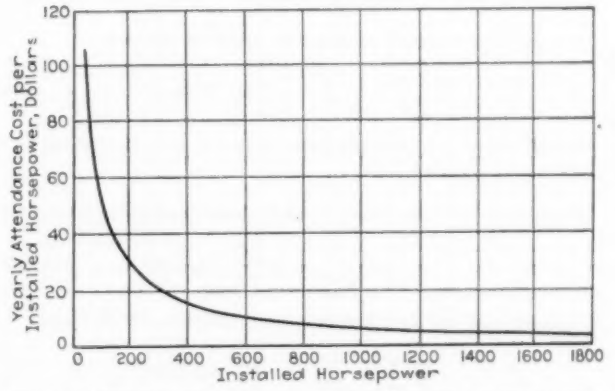


FIG. 21 ATTENDANCE COST OF MOTOR-DRIVEN RECIPROCATING PUMPS

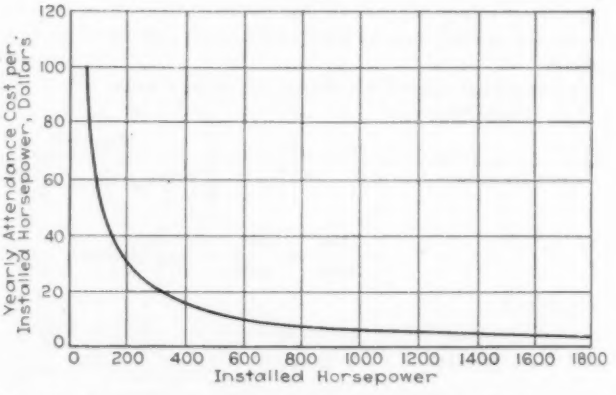


FIG. 22 ATTENDANCE COST OF MOTOR-DRIVEN CENTRIFUGAL PUMPS

(c) *Lubrication.* For Diesel-powered pump stations the lubricating-oil consumption may be assumed at 2000 hp-hr. per gallon of oil. If we designate

m = cost per gallon of lubricating oil (dollars)

the total yearly cost of lubrication for the n stations of the system may be written as follows:

Annual cost of lubrication (Diesel stations)

$$= \left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)\frac{hm}{2000} \text{ (dollars)} \ldots [53]$$

For motor-driven reciprocating pumps, the cost of lubrication may be taken as one-fourth of Equation [53].

Annual cost of lubrication (motor-reciprocating station)

$$= \left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)\frac{hm}{8000} \text{ (dollars)} \ldots [54]$$

For centrifugal stations, the lubricating cost is nominal, and assuming it at one-tenth of Equation [53], we obtain:

Annual cost of lubrication (centrifugal stations)

$$= \left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)\frac{hm}{20{,}000} \text{ (dollars)} \ldots [55]$$

(*d*) *Maintenance, Supplies, and Miscellaneous Station Upkeep.* The yearly maintenance cost of a Diesel installation varies between one and two dollars per installed horsepower per year. If we include supplies and miscellaneous station upkeep expenses in this item, a charge of $g = 0.0005$ dollars per horsepower-hour should give representative results. Hence, for n stations:

Annual cost of maintenance and supplies (Diesel)

$$= \left[\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right] hg \text{ (dollars)} \ldots [56]$$

For motor-reciprocating stations this cost may be divided by 4 and for centrifugals by 10.

Annual cost of maintenance and supplies (motor-reciprocating)

$$= \left[\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right]\frac{gh}{4} \text{ (dollars)} \ldots [57]$$

Annual cost of maintenance and supplies (centrifugal)

$$= \left[\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right]\frac{gh}{10} \text{ (dollars)} \ldots [58]$$

We are now in position to write the equation for the total annual operating expense of the entire system of n stations. Summing up the various component costs just developed, we obtain:

Total annual operating cost for the entire system =

(*a*) *Diesel Stations:*

$$X = (50 + 1.5x)L + \left[\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right]\left[\frac{2194n^{0.725}}{\left[\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right]^{0.725}}\right. + \left.\frac{h\varphi e}{350s'} + \frac{hm}{2000} + hg\right] \text{(dollars)} \ldots [59]$$

in which

$$\alpha = \frac{sLQ^3}{5568E_p},\quad \beta = \frac{\eta^{0.46}\, sLQ^{2.54}}{234E_p},\text{ and } \gamma = \frac{s(z_n - z_o)Q}{5658}$$

(*b*) *Motor-Driven Reciprocating Stations:*

$$X = (50 + 1.5x)L + \left[\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right]\left[\frac{4510n^{0.975}}{\left[\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right]^{0.975}}\right. + 0.164h^{0.66} + \left.\frac{hm}{8000} + \frac{hg}{4}\right] \text{(dollars)} \ldots [60]$$

Based on power cost of 1 cent per kw-hr. at 100 per cent use factor, i.e., $h = 8760$. For $h < 8760$ the cost per kilowatt-hour is assumed according to Equation [51].

(*c*) *Centrifugal Pump Stations:*

$$X = (50 + 1.5x)L + 6000n + \left[\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right]\left[0.164h^{0.66} + \frac{hm}{20{,}000} + \frac{hg}{10}\right] \text{(dollars)} \ldots [61]$$

It must be remembered that E_p in α and β must be based on centrifugal-pump performance in this case.

SECTION III

According to Equation [3] the total annual charges against the system, i.e., the sum of the fixed charges and operating expenses $u = X + Y$ is a minimum when $\frac{dX}{dx} + \frac{dY}{dx} = 0$, and d^2u/dx^2 is positive in sign.

Substituting the equations developed in Sections I and II in (1), and making the differential coefficient equal to zero, we obtain:

(*a*) *Diesel Station System:*

$$\frac{dY}{dx} + \frac{dX}{dx} = \left\{\frac{x^{0.867}LS^2}{\left(S - \frac{a}{nx^5} - \frac{b}{nx^{4.54}} - \frac{c}{n}\right)^2}\right.$$

$$\left[1316 - \frac{1410\left(\frac{5a}{nx^5} + \frac{4.54b}{nx^{4.54}}\right)}{S - \frac{a}{nx^5} - \frac{b}{nx^{4.54}} - \frac{c}{n}}\right] - 1316x^{0.867}L + 100L + 72xL$$

$$\left. - \frac{935\left(\frac{5\alpha}{x^6} + \frac{4.54\beta}{x^{5.54}}\right)n^{0.215}}{\left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)^{0.215}}\right\}[(1 - \sigma)\Delta + R + T] + 10.32$$

$$x\,\varphi L(R + T) + 1.5L - \left(\frac{5x}{x^6} + \frac{4.54\beta}{x^{5.54}}\right)\left[\frac{600n^{0.725}}{\left(\frac{\alpha}{x^5} + \frac{\beta}{x^{4.54}} + \gamma\right)^{0.725}}\right. + \left.\frac{h\varphi e}{350s'} + \frac{hm}{2000} + hg\right] = 0. \quad [62]$$

In connection with this equation it must not be forgotten that the line investment should not become less than indicated in Equation [18]. In other words, the pipe-wall thickness and its diameter should be such that $p' \geq \frac{S(17 + x)}{51x + 17.}$

This will be shown more in detail in the example below.

(*b*) *Motor-Driven Reciprocating Station System:*

For a pipe-line system depending upon motor-driven reciprocating stations, the equation representing the minimum may be written as follows:

$$\frac{dY}{dx} + \frac{dX}{dx} = \left\{\frac{x^{0.867}LS^2}{\left(S - \frac{a}{nx^5} - \frac{b}{nx^{4.54}} - \frac{c}{n}\right)^2}\right.$$

$$\left[1316 - \frac{1410\left(\frac{5a}{nx^5} + \frac{4.54b}{nx^{4.54}}\right)}{S - \frac{a}{nx^5} - \frac{b}{nx^{4.54}} - \frac{c}{n}}\right] - 1316^{0.867}L + 100L + 72xL$$

$$-\left\{\frac{467n^{0.215}\left(\frac{5\alpha}{x^5}+\frac{4.54\beta}{x^{5.45}}\right)}{\left(\frac{\alpha}{x^5}+\frac{\beta}{x^{4.54}}+\gamma\right)^{0.215}}\right\}[(1-\sigma)\Delta+R+T]+1.5L$$

$$-\left(\frac{\alpha}{x^5}+\frac{4.54\beta}{x^{5.54}}\right)\left[\frac{290n^{0.935}}{\left(\frac{\alpha}{x^5}+\frac{\beta}{x^{4.54}}+\gamma\right)^{0.935}}+0.164h^{0.66}+\frac{hm}{8000}+\frac{hg}{4}\right]+10.32x\varphi L(R+T)=0\ldots[63]$$

(c) *Centrifugal Pump System:*

It must be remembered that the efficiency of centrifugal pumps is somewhat lower than that obtainable with reciprocating pumps. Calling this efficiency E'_p, and the corresponding constants α' and β', we can write the following equation:

$$\frac{dY}{dx}+\frac{dX}{dx}=\left\{\frac{x^{0.867}LS^2}{\left(S-\frac{a}{nx^5}-\frac{b}{nx^{4.54}}-\frac{c}{n}\right)^2}\right.$$

$$\left[1316-\frac{1410\left(\frac{5a}{nx^5}+\frac{4.54b}{nx^{4.54}}\right)}{S-\frac{a}{nx^5}-\frac{b}{nx^{4.54}}-\frac{c}{n}}\right]-1316x^{0.867}L+100L+72xL$$

$$\left.-\frac{234n^{0.215}\left(\frac{5\alpha'}{x^5}+\frac{4.54\beta'}{x^{5.54}}\right)}{\left(\frac{\alpha'}{x^5}+\frac{\beta'}{x^{4.54}}+\gamma\right)^{0.215}}\right\}[(1-\sigma)\Delta+R+T]$$

$$+10.32x\varphi L(R+T)+1.5L-\left(\frac{5\alpha'}{x^5}+\frac{4.54\beta'}{x^{5.54}}\right)\left(0.164h^{0.66}+\frac{hm}{20{,}000}+\frac{hg}{10}\right)=0\ldots\ldots[64]$$

Numerical Example

To demonstrate the application of these equations, let it be required that a pipe-line system is to be designed for the transportation of 50,000 bbl. of crude oil per day, $Q = 2080$ bbl. per hour. The total length of the system is $L = 537$ miles, the elevation of the initial station $z_o = 880$ ft., and the terminal 790 ft. The oil to be pumped has a viscosity of 50 S. U. S., i.e., $\eta = 0.072$, and a specific gravity $s = 0.83$. The line is to be designed for best over-all financial efficiency, and preliminary comparisons have resulted in a choice of Diesel-powered stations in preference to purchased electrical power. The expected load or "use" factor of the line is assumed at 7000/8760, i.e., it will be on full-capacity operation for $h = 7000$ hr. per year. The Diesel engines will be operated on pipe line crude for fuel, $s' = 0.83$, costing $\varphi = \$1.25$ per bbl., and the specific fuel consumption of the engines is $e = 0.45$ lb. per b.hp-hr. The mechanical efficiency of the reciprocating pumps $E_p = 0.85$, and the cost of lubrication is $m = \$0.5$ per gal. All maintenance and supplies for the station are assumed at $g = 0.0005$ dollars per hp-hr.

It has also been decided to construct the line of high-carbon steel pipe of a permissible working stress $S = 15{,}800$ lb. per sq. in. The initial and terminal stations on the system are to be equipped with two Wiggins roof working tanks each, $K = 0.8$, and all other intermediate stations with one "floating" Wiggins roof tank.

A general appraisal of the future of this system has developed the desirability of assuming a 10-year depreciation period, hence $\Delta = 6.90$ per cent. Expected taxes are 2 per cent, and money is considered worth 8 per cent to the company. Salvage value at the end of the 10 years is assumed at 25 per cent, or $\sigma = 0.25$.

What is the most economic layout for such a transportation system that will make the sum of the total yearly charges, both fixed and operating, a minimum?

For a pipe-line system based on Diesel-driven pump stations the most economical pipe diameter is given by the following Equation [62]:

$$\left\{\frac{x^{0.867}LS^2}{\left(S-\frac{a}{nx^5}-\frac{b}{nx^{4.54}}-\frac{c}{n}\right)^2}\right.\left[1316-\frac{1410\left(\frac{5a}{nx^5}-\frac{4.54b}{nx^{4.54}}\right)}{S-\frac{a}{nx^5}-\frac{b}{nx^{4.54}}-\frac{c}{n}}\right]$$

$$\left.-1316x^{0.867}L+100\,l+72xL-\frac{935\left(\frac{5\alpha}{x^5}+\frac{4.54\beta}{x^{5.54}}\right)n^{0.215}}{\left(\frac{\alpha}{x^5}+\frac{\beta}{x^{4.54}}+\gamma\right)^{0.215}}\right\}$$

$$\left[(1-\sigma)\Delta+R+T\right]+10.32x\varphi L(R+T)+1.5L$$

$$-\left(\frac{5\alpha}{x^5}+\frac{4.54\beta}{x^{5.54}}\right)\left[\frac{600n^{0.725}}{\left(\frac{\alpha}{x^5}+\frac{\beta}{x^{4.54}}+\gamma\right)^{0.725}}+\frac{h\varphi e}{350s'}+\frac{hm}{2000}+hg\right]=0$$

This equation can be solved only by trial and error. It will also be necessary to determine the minima for a number of values of n, plot the resulting "total yearly costs" of the system on coordinate paper, and choose the most economical combination from the derived curve.

To assist in the solution of this equation, the exponential functions of the pipe diameter x are given in the following tabulation for a number of values of x:

x	x^5	$x^{5.54}$	x^5	$x^{4.54}$	$x^{1.867}$	$x^{0.867}$
4....	4,096	2,165	1,024	541	13.3	3.3
8....	262,200	100,750	32,770	12,592	48.5	6.1
12....	2,987,000	952,400	248,900	79,360	103.3	8.6
16....	16,773,000	4,685,000	1,048,200	292,800	177.0	11.1
20....	63,980,000	16,125,000	3,199,000	806,300	268.6	13.4
24....	191,080,000	44,290,000	7,962,000	1,888,500	377.5	15.7

The constants for this particular problem are:

$S = 15{,}800$ lb. per sq. in.

$E_p = 0.85$

$F = \dfrac{h\varphi e}{350s'}+\dfrac{hm}{2000}+hg = 18.85$

$h = 7000$ hr.

$\eta^{0.45} = 0.2981$

$Q^{1.54} = 128{,}800$

$Q^{2.54} = 134{,}670{,}000$

$a = 0.44sLQ^2 = 850{,}000{,}000$

$b = 10.47\eta^{0.45}sLQ^{1.54} = 179{,}200{,}000$

$c = 0.433s(z_n - z_o) = -32.3$

$\alpha = \dfrac{sLQ^2}{5568E_p} = 848{,}500{,}000$

$\beta = \dfrac{\eta^{0.45}sLQ^{2.54}}{234E} = 90{,}000{,}000$

$\gamma = \dfrac{s(z_n - z_o)Q}{5658\,E_p} = -32.3$

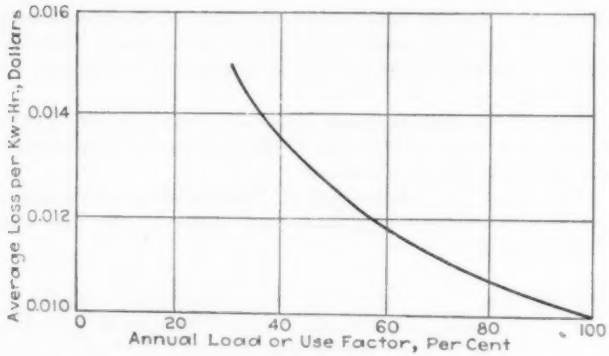


FIG. 23 REPRESENTATIVE ELECTRICAL ENERGY COST

and the evaluation of Equation [62] gives the most economical pipe diameters as a function of the station spacing (Fig. 24).

The working pressures corresponding to the various station spacings are found by means of Equation [21]:

$$\text{Friction head } P = \frac{fsLQ^2}{x^5} \quad [21]$$

or

$$p = \frac{fsLQ^2}{nx^5} \quad [21]$$

and the required pipe wall thickness:

$$t = \frac{xp}{2(S - p)} \quad [7]$$

Substituting the proper values in these equations, and taking account of the slight negative static head of —32.3 lb., we obtain:

n	x	Friction head (lb.)	Friction head —32.3 lb. (lb.)	p (lb.)	t (in.)	B.hp. required, each station
4	16.0	1798	1766	442	0.232	442
8	14.5	2770	2738	342	0.173	342
12	13.65	3715	3683	307	0.136	307
16	13.15	4400	4368	274	0.116	274
20	12.9	4790	4758	238	0.099	238
24	12.75	5078	5046	212	0.084	212

and if we assume each station to be equipped with 25 per cent extra capacity for standby purposes to insure continuity of operation, the installed horsepower will be as follows:

n	x	Installed horsepower, each station
4	16.0	556
8	14.5	431
12	13.65	386
16	13.15	343
20	12.9	300
24	12.75	253

If these values are inserted in Equations [42] and [59], we find the total yearly cost of the systems based on the station spacings as listed. If the resulting "total annual costs" ($X + Y$) are plotted on coordinate paper, the minimum value representing the most economical design may easily be determined by inspection.

The fixed charges and operating expenses for the various station spacings are given in the following tabulations:

FIXED CHARGES (DOLLARS)

n	x	Line investment	Pump-station investment	Station tankage	Total investment	Fixed charges (15.17%)	Interest and taxes oil in line (10%)	Total fixed charges
4	16.0	9,640,000	578,000	144,000	10,362,000	1,575,000	88,600	1,663,600
8	14.5	7,445,000	950,000	264,000	8,659,000	1,314,000	72,800	1,386,800
12	13.65	6,278,000	1,305,000	384,000	7,967,000	1,209,000	69,600	1,278,600
16	13.15	5,702,000	1,600,000	480,000	7,782,000	1,180,000	60,000	1,240,000
20	12.9	5,291,000	1,760,000	600,000	7,651,000	1,161,000	57,600	1,218,600
24	12.75	5,001,000	1,885,000	696,000	7,582,000	1,150,000	56,300	1,206,300

OPERATING EXPENSES (DOLLARS)

n	x	Line maintenance	Station labor	Fuel cost	Lubricating cost	Maintenance and supplies	Total operating cost
4	16.0	39,750	73,500	24,200	3,125	6,250	146,825
8	14.5	38,500	100,000	37,400	4,825	9,660	190,385
12	13.65	37,850	153,000	50,200	6,480	12,960	260,490
16	13.15	37,400	203,000	59,500	7,680	15,360	322,940
20	12.9	37,200	258,000	64,900	8,380	16,760	385,240
24	12.75	37,100	303,000	68,700	8,870	17,750	435,420

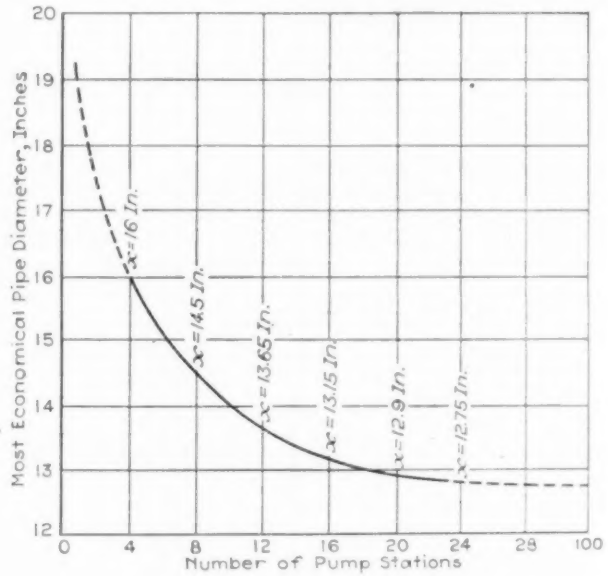


FIG. 24 MOST ECONOMIC PIPE DIAMETERS

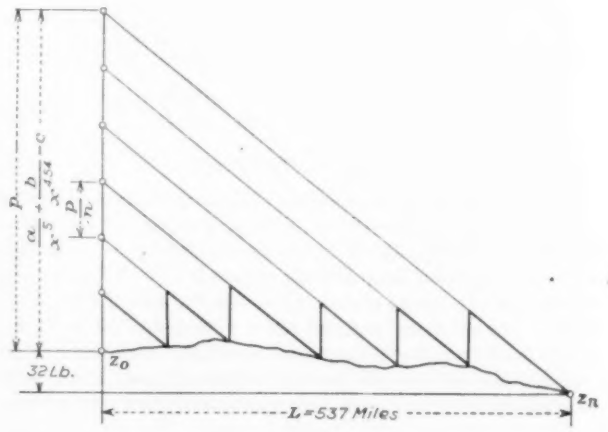


FIG. 26

TOTAL YEARLY COST ($X + Y$) (DOLLARS)

n	Yearly cost	x (in.)	Cost per bbl. pumped
4	1,810,375	16.00	0.1260
8	1,577,185	14.50	0.108
12	1,539,090	13.65	0.1052
16	1,562,940	13.15	0.1070
20	1,603,840	12.90	0.1100
24	1,641,720	12.75	0.1123

From the curve in Fig. 25 we find the most economical system to consist of 13.65 in. inside diameter pipe of a wall thickness of 0.136 in. and twelve pump stations operating at the normal gage pressure of 309 lb. per sq. in. The station spacing must of course be adapted to the profile of the line in such a manner as to equalize the load on

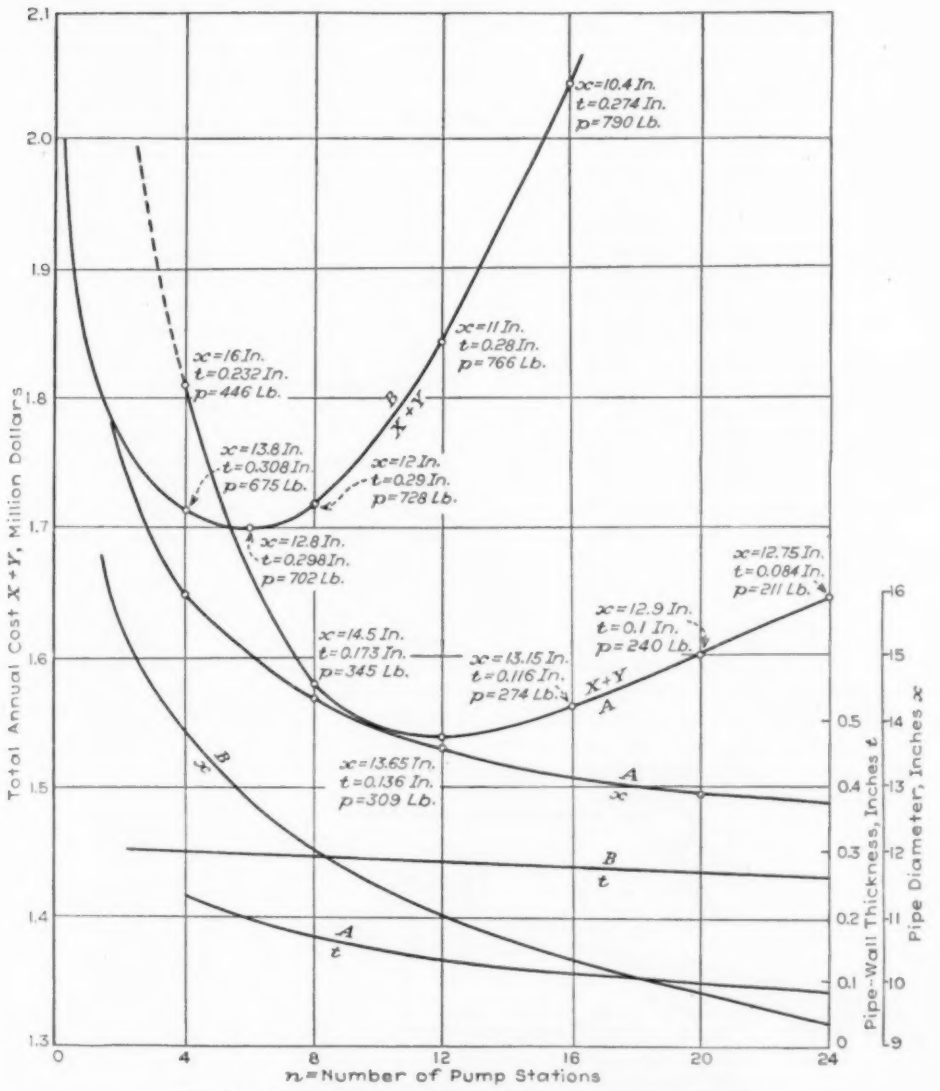


FIG. 25 CURVES INDICATING THE MOST ECONOMICAL SYSTEM

(Capacity of system, 50,000 bbl. per day; length of line, 537 miles; viscosity of oil, $\nu = 0.07 = 50$ S.U.S.; specific gravity, $S = 0.83$; depreciation period, 10 years; depreciation rate, 6.9%; interest rate, 8%; taxes and insurance, 2%; load factor, 7000/8760.)

each pump station to 309 lb. per sq. in., or 309 b.hp. This can easily be accomplished by using the graphical method suggested by Fig. 2.

It is at once apparent that this thin-walled pipe, while strong enough for the internal fluid pressure, does not satisfy the conditions of mechanical strength, and the problem must therefore be recomputed on the basis of a minimum wall-thickness.

$$t' = 0.17 + \frac{x}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots [13]$$

and the consequent minimum line investment:

$$\frac{0.282L(101x^2 + 1734x + 289)}{x^{0.133}} + (100x + 36x^2)L \text{ (dollars)}. \quad [18]$$

SECTION IV

According to Equation [14] $p = \dfrac{S(17 + x)}{51x + 17}$, and if the working pressure of the stations is chosen to stress the steel in the pipe to its greatest permissible value, we obtain:

$$\frac{nS(17 + x)}{51x + 17} = \frac{a}{x^5} + \frac{b}{x^{4.54}} + c \quad \ldots\ldots\ldots\ldots [65]$$

Solving for x, and inserting the given quantities, we obtain the following values of the different station spacings:

n	x (in.)	t (in.)	p (lb.)	B.hp. per station	Installed hp. per station
4.....	13.8	0.308	675	675	894
8.....	12.0	0.29	728	728	910
12.....	11.0	0.28	766	766	958
16.....	10.4	0.274	790	790	988
20.....	9.8	0.268	820	820	1025
24.....	9.3	0.263	846	846	1057

The permissible unit stress on steel in pipe $S = 15{,}800$ lb.

With the linear dimensions of the pipe, working pressure, and required horsepower installation per station thus given, we can, by using the unit costs for investment and operation given in the previous sections, prepare the following estimates

of fixed charges and operating expenses for the various station spacings:

FIXED CHARGES (DOLLARS)

n	x	Line investment	Pump station investment	Station tankage	Total investment	Fixed charges (15.17%)	Interest and taxes oil in line (10%)	Total fixed charges
4	13.8	8,975,000	840,000	144,000	9,959,000	1,510,000	66,000	1,576,000
8	12.0	7,375,000	1,710,000	264,000	9,349,000	1,418,000	49,800	1,467,800
12	11.0	6,415,000	2,660,000	384,000	9,459,000	1,432,000	41,900	1,473,900
16	10.4	5,920,000	3,630,000	480,000	10,030,000	1,520,000	37,400	1,557,400
20	9.8	5,460,000	4,675,000	600,000	10,735,000	1,620,000	33,300	1,653,300
24	9.3	5,080,000	5,715,000	696,000	11,491,000	1,740,000	30,000	1,770,000

OPERATING EXPENSES (DOLLARS)

n	x	Line maintenance	Station labor	Fuel cost	Lupricating cost	Maintenance and supplies	Total operating cost
4	13.8	37,900	49,000	38,000	4,725	9,460	139,085
8	12.0	36,500	102,000	81,800	10,190	20,800	251,290
12	11.0	35,700	155,000	129,000	16,100	32,200	368,000
16	10.4	35,200	205,000	177,500	22,100	44,300	484,100
20	9.8	34,700	256,000	230,600	28,700	57,400	607,400
24	9.3	34,300	305,000	285,000	35,500	71,000	666,900

TOTAL YEARLY COST ($X + Y$) (DOLLARS)

n	x	$X + Y$	Cost per bbl. pumped
4	13.8	1,715,000	0.1176
8	12.0	1,719,000	0.1178
12	11.0	1,841,000	0.1260
16	10.4	2,041,000	0.1400
20	9.8	2,260,000	0.1550
24	9.3	2,437,000	0.1670

Plotting the total costs $X + Y$ against n, the number of stations, we find from curve B in Fig. 25 the most economical system to consist of 12.8-in. inside diameter pipe of a wall thickness of $t = 0.298$ in. The six stations are all expected to operate on a gage pressure of 702 lb. per sq. in., which produces a maximum fiber stress in the pipe of 15,800 lb. at the high-pressure ends of the line. A similar computation based on the assumption that the steel be stressed to less than the permissible maximum would naturally require larger diameter pipe for a given station spacing, and it will be found that the total yearly costs representing such a system will be above those shown by curve B in Fig. 25.

In conclusion, it must be reiterated that the data on unit costs, both for investment and operating expenses, represent the author's viewpoint only, and that such modifications as appear necessary in the light of preliminary study of a given problem must be made so as to reflect actual conditions encountered as nearly as possible.

It is a very significant fact that a slight decrease in the pipe diameter, say to 10.4 in., i.e., the difference of approximately one commercial pipe size, would increase the yearly cost of the system by over $300,000, or $3,000,000 for an operating period of ten years. Such results should be conclusive evidence that proper economic studies for a proposed oil-pipe-line transportation system may produce far-reaching results. It is only too true that many pipe-line systems built during the past were designed on the hit-and-miss system and by rule of thumb without much regard for their financial efficiencies. Alert managements of the present day are ever on their guard, and if the pipe-line-designing engineer can produce basic calculations having such a striking influence upon the net earnings of his company, he will do much to dispel the suspicion of being a tolerated necessary evil, and thereby justify his existence.

Progress in the Petroleum Industry

Contributed by the Petroleum Division

Executive Committee: W. G. Heltzel, *Chairman*, J. W. Hays, *Secretary*, P. L. Guarin, C. F. Braun, H. R. Pierce, and Walter Samans

IN PREPARING its Progress Report for the year 1929, the Petroleum Division has confined its attention to two fields: namely, pipe-line transportation and refining. These have been reported on by engineers especially acquainted with their respective subjects, and their findings appear below.

PROGRESS IN PIPE-LINE TRANSPORTATION[1]

The last three years have marked a transitional period in the pipe-line industry from old and traditional methods to new and better ones. This change has come about in the industry largely through the cooperative efforts of the engineers both in the petroleum industries and those allied with it in the manufacturing of the products and commodities which it uses. The mechanical engineer has been recognized in the petroleum industry by the executives of the various companies, and much of the progress that has occurred during the last three years can be attributed to the efforts of the engineer to adopt new methods. It is the purpose of this report to summarize some of the outstanding developments during the year 1929 in the oil-pipe-line industry.

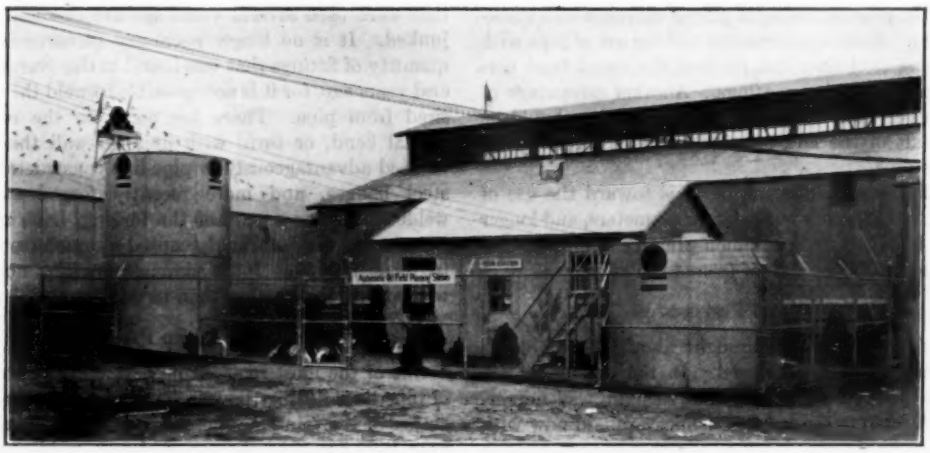


FIG. 1 EXTERIOR VIEW OF EXPERIMENTAL AUTOMATIC PIPE-LINE PUMPING STATION FOR GATHERING SYSTEMS AS EXHIBITED AT TULSA, OKLA., OCT. 5–12, 1929

LINE PIPE

One of the outstanding changes that has occurred in pipe-line equipment has been in line pipe. Three years ago the industry was following the same practice that it had been using for years: lap-welded pipe made of low-carbon steel with a tensile strength of about 48,000 lb. was used almost exclusively. At that time the screwed coupling was used for joining the pipe together. About two years ago seamless line pipe made of steel with a tensile strength of about 48,000 lb. was used in some welded lines which were then being laid. Immediately following the laying of these lines some seamless line pipe with a higher percentage of carbon and with a tensile strength of about 64,000 lb. was used in a long welded line. Since that time seamless line pipe has been used extensively for welded pipe lines. The merit of this class of pipe has been proved by the lack of failures either in tests or in the use since that time. A welded line 200 miles in length was tested without a failure, and no failures have occurred during its two years of service either in the pipe or in the oxy-acetylene welds joining the pipe. During the last year a large amount of autogenous electrically welded pipe has been used in trunk lines in diameter up to 12 in. This class of pipe is lighter in weight than the standard lap-welded or seamless pipe. The autogenous-welded pipe is made of steel with a carbon percentage of from 0.25 to 0.35 and a tensile strength of 64,000 to 72,000 lb. The wall thickness of the pipe is about $^1/_4$ in. The recent tests on a long line in which autogenous-welded pipe was used have proved it satisfactory.

It is understood that one of the steel companies will soon be ready to put on the market a pipe which will be welded by an electrical flash method. The last two years have marked the passing of lap-welded pipe for high-pressure trunk lines. There will be some lap-welded pipe used when the seamless and the autogenous pipe are not available, but less than formerly.

Although the seamless pipe has cost a little more than the lap-welded pipe, it is believed that its merits justify the small increase in cost. A distinct advantage of the seamless pipe is that it does not have welded longitudinal joints and consequently will be considerably less subject to failure than welded pipe. Other advantages in the use of seamless pipe are that it can be worked at higher pressures on account of the efficiency of the joint over lap-welded pipe, and it can be made in higher-carbon steels with higher tensile strength. The use of seamless pipe will permit much higher working pressures than could be obtained with low-carbon lap-welded pipe, which cannot be made in the higher-carbon steel. It will be seen, then, that with higher permissible working pressures the pumping stations can be spaced farther apart and consequently a smaller number of them required than on the standard lap-welded line. The use of this pipe, then, will permit either greater distances between stations or greater capacity between

[1] Prepared by William G. Heltzel.

stations as they are spaced on present lap-welded lines. The use of this seamless pipe should mean a lower overall investment and a considerably reduced operating cost. It is believed that when designing new lines, the higher-carbon steel, of a tensile strength of 64,000 lb. minimum, should be used at least on the high-pressure ends of pipe lines in order to take advantage of the higher permissible operating pressure, and in case it is desired to operate a line at a lower pressure, the "reserve strength" in the pipe would be available in the future if additional capacities were required. A design using the higher-tensile-strength pipe on the high-pressure end would permit additional capacity in the future, when it was needed, making it unnecessary to build loops to give that additional capacity.

The electrically welded pipe has proved its merit in service and it is believed that the joint will prove reliable. This reference pertains to the longitudinal weld along the pipe as well as to the circumferential weld made in the field to join the lengths of pipe together. What has been said as to the merit of high-tensile seamless pipe pertains to the autogenous-welded high-tensile-strength pipe also. The advantage of the autogenous-welded pipe is that it is lighter in weight per foot and consequently the freight cost is less, the stringing and laying cost is less, and the overall investment is smaller. The one question about the autogenous-welded pipe of $^1/_4$ in. thickness is that of corrosion. Engineers are asking themselves, "Will the pipe of $^1/_4$-in. wall thickness have the same life as the standard pipe with heavier walls?" It is realized that soil corrosion will cause failures in both classes of pipe, but what the relative life is for pipe of different wall thicknesses is not known. Some engineers are making use of pipe with lighter walls, hoping that they can prevent the metal from corroding by applying protective coatings. Another advantage of the pipe with thinner walls is that a greater capacity should be obtained on account of the larger inside diameter for the same normal size of the pipe.

In the design of new pipe lines the trend is toward the use of higher tensile strength, thinner walls, larger diameters, and longer lengths of pipe. It is becoming common practice in oil-pipe-line construction to use pipe in lengths of from 40 to 45 ft.

Pipe Joints and Fittings

The welding of pipe lines has brought about a remarkable change also in the type of joints used. In the pipe lines laid previous to about three years ago the screwed joint was universally used. However, few or no trunk lines are laid now with screwed joints, because the pipe is joined together either by gas or electric welding. The screwed joint has almost become obsolete for trunk-line work; however, it will continue to be used to some extent for temporary field gathering lines.

Until recent years the screwed joint was the best type of joint available for construction work, and consequently all of the old lines are joined by screwed couplings. The history of these old lines is filled with repeated failures in the couplings. The lines have pulled out of the joints and leakage has occurred through the screwed coupling when the line was expanding or contracting. The result has been that large losses of oil have occurred on account of the screwed joint. It has been learned recently also that the leakage of oil from the screwed coupling has resulted indirectly in severe corrosion of the lines where leaks have occurred. It is becoming common practice among pipe-line companies, when taking up old lines that are to be relaid, to cut out the coupling and threads and bevel the pipe for welding. And when old lines are uncovered and reconditioned it is the policy of some of the companies to put a light weld on each side of the coupling to prevent leakage and, indirectly, corrosion. The four methods used at present for joining welded pipe are:

a The butt joint with the ends of the pipe beveled at 45 deg. for gas welding. This type of joint is used in laying pipe with a standard wall thickness, and the joints usually are gas welded.

b The bell-and-spigot joint, with a special dam on the spigot end of each joint, is being used on the pipe of lighter walls for gas and electric welding.

c The plain bell-and-spigot joint without the special dam is being used also for gas and electric welding.

d A bell with expanded ends of the pipe butting together, beveled, and with a "back-up" ring on the inside fitting into the expanded ends. This type of joint is being used for gas and electric welding. It provides for good welding penetration and gives good strength.

It is understood that some development work has been done on another type of joint. This joint is made in the field by a hydraulic machine, which recesses a ring groove in the wall of the spigot end of a joint of pipe; the bell joint is then fitted over the spigot end and by hydraulic pressure a ring groove is recessed in the bell wall to fit into the corresponding recess in the wall of the spigot where they join, thereby providing strength in the joint against pulling apart. After the pieces of pipe are joined by the hydraulic recessing, the bell end is welded to the spigot end of the other joint of pipe.

A few years ago it was common practice to use heavy cast-iron fittings consisting of ells, tees, flanges, manifold barrels, valves, castings, etc. The use of welding has brought about a beneficial change in fittings for pipe-line work. The heavy cast-iron fittings that were used several years ago are obsolete and ready to be junked. It is no longer necessary to carry in stock the large quantity of fittings that was found in the average warehouse several years ago, for it is now possible to weld the type of fitting desired from pipe. There has come on the market recently a special bend, or turn, with uniform wall thicknesses that can be used advantageously in pipe-line construction work. Forged steel flanges, and more recently forged steel flanges with welded necks as a part of the forging, have replaced the cast-iron flanges which formerly caused so much trouble through their frequent failures. It is common practice now to use flanges welded into lines rather than to use screwed flanges.

Welded Pipe Lines

One of the most remarkable developments in the construction of pipe lines during the last three years has been the welding together of the joints. The most marked development during the year 1929 has been the use of electric welding for the joining of pipe together in the case of trunk lines. It is known now that the gas-welded line is reliable, and it is believed that the electrically welded line will prove likewise.

When the first gas-welded lines were laid, there was some question about the reliability of the welds and the possibility of "icicles" on the inside of the weld holding up the scrapers in their passage through the lines. In the construction of 200 miles of 8-in. line, not one failure occurred in the tests. After two years of operating no failure has occurred. A leak has not been reported on this line either on the test or in operation. In a line about 400 miles long about five failures occurred when the line was tested. These failures resulted from the pipe's being roughly handled when the pipe line was put into the ditch. However, no failures occurred on this line during the following year of operation.

Scrapers have been put through the entire length of this 600 miles of pipe line, and in no case has a scraper been held up on account of icicles at the welds. It is believed that the electrically welded line will give results equally reliable. Welding has eliminated the many leaks and the loss of oil that occurred in the lines with screwed joints. Welding should result in a much

smaller leakage cost, and certainly it will eliminate much of the corrosion caused by the many oil leaks from the couplings. As a result of the reliability of the welded pipe line, higher operating pressures can be carried and greater security of transportation is assured. It may be that the reliability of the welded line will pave the way to automatic pumping stations.

Pumping-Station Machinery

About 12 years ago the Diesel engine began to replace the steam engine for pipe-line pumping. The pipe lines built since that time have pumping stations equipped with only Diesel engines. However, on the old lines a few steam engines remain. The Diesel unit gave much higher efficiency and consequently it was exclusively used on new pipe lines up until about two years ago. The year 1928 marked the advent of electric-motor-driven pipe-line pumps for oil-trunk-line service. There has been considerable controversy over the economical use of electric motors for pipe-line pumping, and that question has not yet been settled. It is known, however, now that both motor-driven centrifugal and motor-driven reciprocating pumps have proved reliable in operation. If it can be proved that it is more economical, or equally economical, to use electric motors than oil engines for driving pipe-line pumps, then the trend will certainly be toward the electrification of pipe-line pumping stations for newly constructed lines. It will hardly be economical to convert the present oil-engine units in old pipe-line pumping stations to electrical units since the fixed charge is already established.

Where existing pipe-line systems are being increased in capacity, the trend is toward replacing smaller Diesel engines at the pumping stations with larger units. The early oil engines for pipe lines were built in capacities up to 250 and 300 hp., but the more recent installations are units of 750 to 800 hp. The smaller units in the pumping stations are being replaced when the capacity of the line is increased on account of the increased maintenance and labor cost on a number of smaller units. Just as the trend is toward large oil engines, so it is also toward the use of large reciprocating pumps. Some of the recent installations of reciprocating pumps have been units with capacities of 42,000 to 46,000 bbl. per 24 hr. The features of these pumps as compared with the earlier type of pipe-line pumps are sturdier frames, larger bearings, and better gearing.

Considerable trouble has been experienced in pipe-line pumping with the breakage of discharge lines between pipe-line manifolds and the discharge pumps, and of pump parts and other equipment. Some recent investigations have shown that this breakage has resulted from pressure surges in the pipe lines. It has been recommended that air chambers on the discharge side of the pump be used to eliminate this damage. Many of the pipe-line companies have accepted these recommendations, and much of the trouble has been eliminated.

The trend is toward the use of motor-driven pumps for field gathering stations, which have a comparatively short operating life as compared with trunk-line stations. It has been found that the station with a low investment cost is more desirable for field gathering stations on account of the fact that in the method used in the oil fields today a large amount of flush oil is produced within a comparatively short time. The production of a large amount of oil in a short interval of time means a larger gathering system and more stations than were used when fields were developed gradually. These pumping stations for gathering systems have a comparatively short life, and the investment cost must be kept low. Both motor-driven centrifugal and the reciprocating pumps are being used in these field stations. However, it has been found that the reciprocating unit is more desirable on account of its higher overall efficiency. It is probable that the future field gathering stations will have motor-driven reciprocating pumps with centrifugal pumps as spares or for emergency use.

Automatic Pipe-Line Pumping Stations

The use of the electric motor for pipe-line pumping stations has brought about the possible use of automatic control for these stations. It is believed now that automatic control can be used for smaller pipe-line gathering stations. It is believed, further, that after automatic-control equipment has been worked out for this class of station and more confidence is gained in it through reliability of operation, automatic control can be used for trunk-line work, especially where the motor-driven centrifugal pump is employed.

At the recent International Petroleum Exposition held in Tulsa, October 5 to 12, 1929, a full-sized experimental automatic oil-field pumping station was on exhibit. This exhibit was arranged through the Scientific and Technical Committee of the Exposition and was received favorably by pipe-line men, but it was pointed out that certain features had yet to be worked out to make the station fully automatic and foolproof. The exhibit, which is shown in Figs. 1 and 2, demonstrated the following features of automatic control:

a Starting up and shutting down motor-driven pump by a liquid-level instrument actuated by the pressure head exerted by the fluid in the tank.

b Automatically controlled and electrically operated gate valves on the discharge and filling lines.

c Automatic shutting down of motor-driven pump by high- and low-pressure protective gages. This automatic feature was used to demonstrate how the motor-driven pump could be shut down for an excessive increase of pressure in the line or a drop of pressure in the line as a result of a break.

d Automatic starting and shutting down of the motor at a definite time by a time clock.

The information gained from the operation of this experimental station showed that it will be necessary to add the following automatic features of the station to make it foolproof.

a Automatic control of the motor-driven pump by a flow meter, such as the venturi. Thus it is believed that the shutting down of the pump can be made foolproof for a break in the line by using a pressure-protective equipment and a flow meter combined; for a drop in pressure or an increased delivery of fluid usually means a broken line. With a centrifugal pump a break can occur in a line without any drop in pressure being indicated on the recording pressure chart; it is characteristic of a centrifugal pump to maintain its pressure with an increased delivery when a break occurs, provided the break is not too near the pump. Therefore it is believed necessary to adapt the flow meter to shut down a centrifugal pump when a break occurs in a line giving an increased delivery, even though a drop in the pressure does not occur.

b An automatically controlled and electrically operated bypass valve must be developed for use on the discharge pump in starting up so that the pressure is built up gradually with the closing of the bypass valve.

c The proper functioning of this control equipment will depend upon the elimination of the pressure surges on the discharge side of the reciprocating pump. Therefore it is believed necessary to develop an automatically charged air chamber to damper the pressure vibrations.

d It is believed that some work should be done on remote control of pipe-line pumping stations.

Construction of Pipe Lines

Although the use of welding in pipe-line work has resulted in more reliable lines, it is taking more time to lay welded lines than was required to lay screwed pipe, although more labor-saving machinery has been used for this construction work than was used four or five years ago. One reason for this delay is probably that the men who laid screwed lines are yielding their places to younger men who are learning the practice of laying welded lines instead. It will probably take a few years for these men to eliminate the time delays in this construction work. Another element that enters into the laying of welded pipe lines is the weather. When the screwed lines were laid the pipe-line crews were on the job in all kinds of weather. Each man was at his post in the morning at the start, and carried on even in the most severe weather. Each man had his part and kept active throughout the day, and in that way could keep warm when the weather was cold. Conditions are a little different now with the crews laying welded lines. Less physical energy is required on the part of the men, and it is a common sight along pipe lines that are being laid in the winter to find men standing around fires to keep warm. This fault is not so much in the men as it is in the fact that the crews that laid screwed lines were organized differently from those that lay welded lines. Something must and will be done to speed up the construction of welded lines. Already developments have taken place in the speeding up of the electric welding, and it is likely that the time required to lay welded lines will be materially lessened during the coming year. Each year marks the use of additional and more improved labor-saving machines in the construction of oil pipe lines.

Pipe-Line Tankage

The pipe lines built recently have been designed to make use of a smaller amount of tankage for storage at the pine-line stations located along the trunk lines. This condition is especially true on the lines that are using motor-driven centrifugal pumps. This policy of carrying the larger amounts of storage at strategic points and only a small amount of tankage at the relay pumping stations indicates the present trend in the use of pipe-line tanks.

As a means of conserving the light vapors in petroleum, pipe-line companies are making use of the floating roof, especially at the pumping stations where the amount of petroleum handled through the pipe-line system is checked for volume. It is believed that where the floating roof is used at the relay stations on working tanks it should be used only on a tank with a smaller capacity than that of the 55,000-bbl. tank. The use of a 10,000-bbl. working tank would probably result in a smaller maintenance cost, less evaporation, and less trouble from water that might get into the tank. The point might be made that where the oil is not delivered into a large tank, say, a 55,000-bbl. one with a steel roof, serving only as a surge tank on the line, no large amount of evaporation occurs on account of the liquid in the tank standing at an almost constant level; but it is to be remembered that a rather large vapor space exists in the tank and that breathing will result with a change of temperature. Where the floating roof is not used it is common practice now on almost all tankage, except in West Texas, where the oil vapors are very corrosive, to use welded steel roofs which are vapor tight and are equipped with flame-proof venting equipment. In West Texas where corrosive oils are being handled, the wooden roof with insulated top, equipped with lightning protective equipment, is being used.

Some experimental work is being carried out in West Texas on the use of all-aluminum and part-aluminum tanks in sizes up to 1000 bbl. to eliminate the corrosion caused by the vapors from the oil produced in that region. The results which have been observed from the use of these tanks are said to be satisfactory.

Aluminum paint has been used extensively for painting steel oil tanks to reduce evaporation losses that occur in the storage of petroleum. A recent development has been the use of aluminum foil to coat the roofs of the tanks. It is claimed that the tests indicate that a great amount of heat is reflected from the tank, resulting in a much lower temperature in the vapor space and at the surface of the petroleum, thereby reducing the evaporation through breathing losses.

Corrosion of Pipe Lines

One of the largest maintenance costs in the operation of oil pipe lines is the repairs made necessary by the corrosion of pipe. These pipe lines operate at pressures as high as 800 lb. per sq. in. and consequently the corrosion of the walls affects the operating efficiency of the system. The American Petroleum Institute has undertaken a study of the corrosion problem, and considerable has been learned during the last two years as to its extent and as to some of the faults in the methods used in protecting the lines against corrosion. During the last three years much reconditioning of pipe lines has been carried out, and protective coatings have been applied to these lines. During the last year considerable doubt has been expressed among pipe-line men as to the effectiveness of these coatings, and it has become the policy of some companies to delay the reconditioning of pipe lines until material and methods providing for an effective coating have been found. The practice now of some of the companies is to recondition the lines where corrosive conditions are known to exist. The use of accurate records as to the failures in pipe lines due to corrosion is assisting materially in locating the corrosive areas along the pipe line. In the meantime the corrosion committee of the American Petroleum Institute is obtaining some valuable information, which in time will be correlated and the question of protective coatings very much clarified. It is certain that if an effective protective coating can be found for the protection of pipe lines against soil corrosion, pipe with thinner walls and made of steel of high tensile strength will be used with confidence in the design of pipe lines, resulting in lower investment costs.

Economic Advantages of Joint Ownership in Constructing New Pipe Lines

About three years ago, two of the major oil companies built a long trunk pipe line under a provision of joint ownership. During the year 1929 two other major oil companies built a long trunk line under joint ownership. The advantages in such an arrangement are:

- *a* Risk reduced for each company.
- *b* Pipe line can be kept supplied with oil better than when owned by one company.
- *c* Use of one large line instead of two smaller lines with the same or smaller number of operating stations.
- *d* Materially reducing operating expenses by using one large-capacity system by two companies instead of two separate systems by two different companies.
- *e* Greater operating efficiencies can be obtained in one large system than in two smaller systems

From the engineering and economic viewpoint the joint ownership of newly constructed pipe lines has distinct advantages.

Pipe-Line Systems Affected by Economic Changes

An increasing amount of crude oil is being transported to the refineries on the Eastern Seaboard and Gulf Coast. The large amount of cheap oil that has been made available in Venezuela and in West Texas has resulted in the large amount transported by tanker. About five years ago most of the oil was being delivered from the Oklahoma and Kansas oil fields to the Eastern Seaboard refineries by pipe line. The development of the Vene-

zuelan and West Texas crude oils has affected the business of the pipe lines crossing the state of Pennsylvania, and some of these have been sold for gas lines. West Texas crude oil is being delivered to Gulf ports, transported by tanker to the Atlantic Seaboard, and pumped by pipe line west as far as Franklin, Pennsylvania.

An extension of oil trunk lines has been made necessary by the policy of the major companies providing for nationally distributed products. This policy has resulted in the building of refineries in the principal market zones and the extension of the trunk pipe-line systems to these refineries.

The hydrogenation process used in the refining of petroleum may affect pipe-line transportation of petroleum, in that the increasing demand for gasoline can be supplied through the use of this process rather than through an increased crude-oil delivery.

When the hydrogenation process can be used economically for converting heavy oil into gasoline, it is possible that the heavy oils that cannot be transported economically will be refined near the source of production and the gasoline transported by pipe lines.

Although gasoline has been transported through pipe lines for distances as great as 100 miles, a new development has been the converting of an 8-in. oil line that has been idle into a gasoline line to transport gasoline from the Atlantic Seaboard into and across the state of Pennsylvania and into the Ohio Valley. This development is significant, because it may mean the beginning of gasoline transportation by pipe lines at a much lower transportation rate than the present tank-car transportation cost.

PROGRESS IN OIL REFINING[2]

Crude oil is coming into refineries both by pipe lines and tankers, the preferred way depending upon location of refineries and source of crude. The Eastern Seaboard refineries obtain most of their oil by tanker, and there has been a strong tendency to provide centrifugal pumps on the ships, usually electric-motor-driven, each pump handling about 1000 gal. per min. at 125 lb. pressure, this maximum pressure being limited by the strength of the unloading hose and the possibility of leakage at its wharf connections.

If tanks into which crude is being pumped are too far from the wharf, or where the unloading rate is very high, it is customary to install booster pumps on shore, of the multi-stage centrifugal type, motor-driven.

In either case, safety semi-automatic controls are provided by means of which pumping is stopped from either ship or dock by an ordinary fire-alarm pull box. Hydraulic automatic shut-off valves are also provided in the pumping lines, closing off the pipe lines in case of a break.

Tanks and Tank Roofs

Tankage for receiving crude oil in refineries is being made larger as the capacity of tankers is increased, and also depending on the size of the refinery. Eighty thousand barrels is becoming a standard refinery size, and in many cases the same size is used for gasoline storage. These tanks are still made of riveted construction, although on some smaller tanks electric-arc welding has been applied experimentally on bottoms. The roofs of the tanks are almost entirely electric-arc welded where no fire hazard exists, and many are trying some type of floating roof or a roof of similar construction, the main purpose being to keep oil in contact with the steel surface to avoid loss of light ends in the vapor space, or to prevent breathing within certain temperature ranges by holding the vapor space at pressures varying from several ounces to one pound per square inch.

[2] Prepared by Walter Samans.

Refining Stills

The development of stills is so rapid in many types that only a few of the outstanding features can be mentioned.

Fractionating stills, made up of tube heaters in combination with fractionating towers, commonly termed "bubble towers," are being built for a capacity of 10,000 and 12,000 bbl. per day, and units of 16,000 bbl. capacity are being planned.

Similar stills are being considered for the making of asphalt from heavy crudes, and the fractionating is done in two stages, using vacuum on the second stage. The use of vacuum materially increases the tower diameters, thereby involving not only very complex construction and arrangement, but also bringing up questions of maximum shipping dimensions which materially affect final construction costs.

Vacuum distillation is being rapidly developed on account of close fractionation and the larger production of valuable lubricating products, due to less loss resulting from overheating, which is apt to occur in the so-called atmospheric pipe still. Practically every refiner is interested in this process, and many have made trial installations. The initial cost and the size of apparatus have been the main drawbacks to rapid development heretofore.

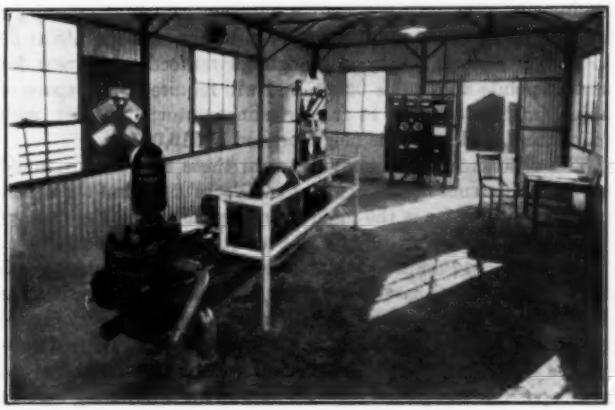


Fig. 2 Interior View of Experimental Automatic Pipe-Line Pumping Station Shown in Fig. 1

As regards cracking stills, vapor-phase processes are gaining headway, in spite of high initial costs and difficulties with fixed as and coke formation, due largely to the anti-knock properties of the gasoline produced. While similar properties in cracking-still distillates are sought after in so-called liquid-phase cracking stills, there is evidently real competition between different methods, and the development in each refinery will depend largely on the type of equipment already installed.

In cracking stills, the maximum temperature of 950 to 980 deg. fahr. in the outgoing oil, which may easily result in 1100 deg. on the hottest tubes, together with an outlet pressure of close to 1000 lb. has resulted in the application of chromium-nickel alloy tubes, at an initial cost many times that of the carbon-steel tubes, in all those portions of the tube heater subject to the higher temperatures.

Tube lengths of 30 ft. are quite common, and the established size of 4 in. O.D. $\times$ $^1/_2$ in. thick is being supplanted by even larger and heavier tubes, with possibilities of greater lengths as capacities are increased. At least one tube manufacturer is installing a drawbench for tubes 40 ft. long, the initial reason being that this length is required by the large-capacity fractionating stills where pressures may go only as high as 300 or 400 lb.

The object in all cracking stills is, of course, economical conversion of low-gravity fractions to a distillate that can be incorporated into a motor gasoline, and a satisfactory process re-

quires that the fixed gas and corresponding quantity of coke be kept to a minimum.

Hydrogenation of Petroleum. By the introduction of hydrogen under pressures from 1400 to 4200 lb. and in the presence of a catalyst, it is now possible to convert practically all of the original oil into gasoline and other products. Carbon formation is actually eliminated and the production of fixed gases reduced to a minimum. Two plants which will employ this process are now being constructed by the Standard Oil Company of New Jersey at Bayway, N. J., and Baton Rouge, La.

Pumps

Hot-Oil Charging Pumps. Charging pumps for stills, particularly cracking stills, are of interest to mechanical engineers from the viewpoint of high pressure and temperature and the need for corrosion-resisting metals. A reciprocating steam pump for a capacity of 6000 bbl. throughput of 600 deg. fahr. oil at 1400 to 1600 lb. discharge pressure, operating with crank and flywheel on the compound steam end, will use 20 lb. of steam per l. hp. with condensing operation, and cost in the neighborhood of $28,000, including foundation. Its floor space of 12 ft. × 32 ft. is its main drawback, particularly in the application to existing equipment. On the other hand, a ten-stage centrifugal pump for the same capacity, requiring a 400-hp. motor, will operate at 50 to 55 per cent efficiency, although guaranteed when new for several points above this figure, and will require a floor space of approximately 5 ft. × 14 ft., including motor; the cost, with foundation, will be in the neighborhood of $16,000.

The difference in economy between these two pumps would save the difference in cost in about two years' time, but the uncertain factor thus far is the maintenance expense and the damage that may be occasioned by small fires in the pump house.

Motor-Driven Pumps. Motor-driven reciprocating pumps with intermediate gears have been tried with satisfactory results, as they give very satisfactory operation, but must be of very rugged construction to avoid excessive wear on gears. The main objection to them, particularly the larger sizes, is that variable speed is not possible except with special motors for alternating-current or direct-current motors which may not be adapted to the current available, and in either case provide some additional fire hazard on account of sparks from the commutators.

Charging Multiple Stills. Charging pumps for cracking stills, as well as fractionating stills, have been applied to as many as twenty stills for one pump; however, it is then necessary to maintain the maximum pressure that any of the stills may require, this pressure being affected by friction losses due to carbon collecting in the tube heaters, in order to maintain flow control for each still. The centrifugal charging pump lends itself well to this service, particularly since the larger the pump the greater the efficiency, but this scheme has not been sufficiently used to lead to general adoption at this time.

Corrosion in Pumps. Corrosion in pumps is accelerated by reason of the high velocities through valve passages on reciprocating types and impellers on centrifugal types, requiring in the first instance stainless-steel plungers and valve parts, and in the second, chromium or nickel-chromium alloys. The initial cost and manufacturing losses on these materials add greatly to the final cost of the pump.

Automatic Control of Stills

Full automatic control on stills has not been possible, due to imperfections in the apparatus offered and the severe requirements for service conditions, oils containing both finely divided solids, mostly carbon, and corrosive elements which cannot be eliminated economically.

Of course the usual pressure, speed, and temperature controls used in large boiler plants are applied to oil stills, and there are but few installations which do not have flow meters to indicate in some measure the quantities of oil being handled in the important parts of the system.

Their successful application, however, is confined mostly to the larger refineries where the instruments can receive proper care and repairs by the plant force.

Refinery Processes Require Technically Trained Men

Just as in large boiler plants, it is found that technically trained men are required for the operation of important refinery processes, particularly still batteries, and for the proper supervision and maintenance of the equipment which is designed on high-grade technical principles. While chemical engineers are preferable in petroleum refining-process operations, the actual operating and maintenance work has been equally well handled by mechanical engineers.

Gasoline Recovery and Stabilization

In gasoline recovery and stabilization the maximum operating pressures are in the neighborhood of 300 lb. per sq. in., and while both compression and absorption plants, or a combination of these, are being used, depending upon local conditions, the greater initial cost of the absorption plant in connection with the recovery of gasoline from still gas is warranted by the greater percentage of recovery of the lighter hydrocarbons. There seems to be no limit to the minimum quantity of gasoline per 1000 cu. ft. which can be economically recovered, this varying from three to fifteen gallons, depending upon the time of year and the temperature of the cooling water available, and of course the composition of the still gas.

General Practice

Treating Cracking Distillates. In the treating of cracking distillates, the tendency is very marked toward obtaining the maximum recovery of anti-knock fractions, which means the supplanting of acid treatment with processes similar to the Gray vapor-phase treatment.

Processing Lubricating and Paraffin Products. In the processing of lubricating and paraffin products, centrifuge dewaxing is making rapid strides, as all the more important refineries have such an installation.

Contact filtration is being used to a greater extent, but is limited to conditions where less than the highest-quality product is wanted.

Refrigeration is being used to remove waxes from lubricating oils and make them suitable for low-temperature operation, the oil being chilled to as low as —40 deg. fahr.

Drying of Fullers' Earth. In the drying of filtering clays, usually fullers' earth, the wedge furnace or one of similar design, consisting of a number of floors of refractory material over which the clay is moved by rotating arms counter to the flow of hot gases from a separate combustion chamber, has practically supplanted the old-type rotary kilns and various types of gravity furnaces. The expense of installing furnaces of the wedge type, however, has not permitted their general adoption by small refineries.

Acid Recovery. For sulphuric acid recovery plants, the vacuum system seems to be preferred in locations where occasional fumes from other types are apt to cause public nuisances, although, of course, the combination of acid concentrators with electric precipitators is still in use and being installed.

Multiple Heat-Transfer Units. Heat-transfer equipment for the larger still units is being mostly made in multiple-shell designs, although there is a tendency to standardize for convenience of stock and maintenance.

Corrosion of Equipment. Corrosion and deposits on tube surfaces are the main elements affecting the mechanical design, but there is a strong tendency in favor of making designed pressures much greater than working pressures, and large allowances for corrosion. Corrosion, particularly in gasoline condensers and exchangers, is most noticeable on initial condensation of the distillates, and chemical treatment of the charge is still applied as heretofore.

Piping. The adoption of the new American Engineering Standards for piping is becoming general, and for hot oil and vapors, seamless steel pipe has been generally adopted in place of lap-welded pipe.

Welding of the Lines. Welding of plant piping is coming into use where the pressure is not over 150 lb., but it is not yet thought feasible for hot-oil and vapor lines on account of the need for taking down lines for cleaning and for inspecting them for corrosion.

Power-Plant Practice

Steam boiler plants for refineries are being built for as high as 535 lb. pressure, with the needed superheat for turbine generators which may exhaust at sufficient pressure for process-steam distribution sometimes by the use of bleeder-type turbines; but, where possible, the plant is designed to balance the power requirement with process steam.

Steam is further superheated for process work, varying from 800 deg. fahr. total temperature at 10 lb. pressure, to 500 deg. at 120 lb. pressure.

It is still the practice for each refinery to generate its own electric power on account of this need for process steam, but in some special cases power has been purchased on account of remoteness of power use, compared to the location of steam plant, or some particular advantage in the cost of purchased power.

In the application of power, the possibility of gaseous atmosphere around pumps handling petroleum and its products makes it customary to place a fire wall between the motor and pump, surrounding the shaft by a stuffing box.

In some cases, particularly on foamite and water pumps, dual drive is applied with a motor at one end and a steam turbine or gasoline engine at the other. These run in sizes from 150 to 300 hp.

While a brush-shifting-type motor has been used in a few instances for a variable speed on reciprocating power pumps supplied with reduction gears, usually of the herringbone type, they have not gained much favor, because of first cost and the possibility of sparking commutators' igniting gas, even though the motor be in a separate room.

Production Engineering in the Printing Plant, a Factor That Can Be Merchandised

By H. R. LEWIS,[1] HAMMOND, IND.

As a result of an analysis of plant, equipment, personnel, costs, and merchandising methods the company with which the author is connected specializes on the manufacture of hard-bound books. A straight line system of production was worked out which made it necessary to enlarge various departments. The author tells of the changes that were made and the result accomplished.



IN THE present era of keen competition in every industry and between industries, together with the attendant struggle for lower costs, there is a still greater responsibility being placed upon the engineering of production.

To no industry is this subject of more vital importance than to those who manufacture to contract. Many manufacturers in many different lines whose business requires that they manufacture to contract have developed their plan of production to the point where it may be said that they have proved beyond any doubt the efficacy of a well-engineered production plan.

In the author's comparatively short experience in the printing industry, he feels inclined toward the belief that this particular phase of manufacture has not been developed to as high a degree in the printing industry as it has been in many other industries. The short experience of our company along this line tends to verify this. Although all plans have not yet been developed to the point which is considered the ultimate goal, yet there is every reason to believe that such experiences as we have undergone and such facts as we have proved to ourselves will undoubtedly be of great interest.

It may be well to give a brief picture of the history of the W. B. Conkey Company as a basis of comparison between the conditions which formerly existed and those which exist in the plant today. As some of the changes contemplated have not been completed, it will be impossible to show diagrams and illustrations of the conditions existing before applying the principles of production engineering. The W. B. Conkey Company has been in existence for some fifty years. The plant now occupied was built about thirty-five years ago. It was so well planned and constructed that, at the time of its completion, it was considered to be far ahead of its day. This plant is of one-story construction, sawtooth roof design, and contains 300,000 feet of floor space.

Sensing the trend of business, it was decided that if the company was to maintain its position, certain changes would be necessary. A complete analysis of the plant, the equipment, personnel, costs, and merchandising methods was made, extending over a period of approximately a year. The findings indicated that certain changes would have to be made throughout the company, and a definite program was formulated and put into practice. As a consequence, three years of this program have now passed, and already some very definite accomplishments can be pointed out.

Throughout the life of the company it has been the policy to do a general printing business. The first tangible result of the analysis was the determination that with the type of plant, the character of equipment, and experience of the people, it was best qualified for the manufacture of hard-bound books that could be produced completely in the plant, from the composition to the finished product, with flatbed-press equipment. This was probably the most important decision, and the results so far have indicated the correctness of this decision.

While the decision to specialize on this particular type of work has caused the passing up of a considerable volume of business that might otherwise have been secured, yet this loss of business has been offset to a very desirable degree by the improvement in the service which it has been able to maintain and the costs which it has been able to reduce.

Therefore, this paper will deal primarily with the methods and equipment which it is believed must be employed for the specialized mass production of hard-bound books and catalogs.

Having reached the decision to specialize in the mass production of hard-bound books of all kinds, an analysis of the equipment and the location of equipment by each department was undertaken. Excessive material-handling costs due to backtracking of materials, improper storage, and absence of progressive assembly were disclosed.

After a careful study to determine the character of work best suited to the equipment, taking into consideration the most modern processes, the question of obsolescence of equipment, and the balance of equipment for the best coordination with the various departmental operations, a straight-line system of production was worked out which necessitated the enlargement of the various departments to bring about free movement of materials and the proper storage of work in process.

Engineers and architects were called in, and a plan of enlargement was worked out by the erection of two additional rooms and changing of partition walls which increased the floor space of each department. This resulted in a more efficient utilization of the original floor area.

The boiler-room equipment consisted of two 150-hp. and one 300-hp. boilers. Coal was the fuel employed and the boilers were hand-fired. Feeling that this department should receive first consideration, heating and power plant engineers were called in. Data were compiled on automatic coal-handling equipment, stokers, pulverizers, and oil burners.

After comparing the results of this analysis and the factors which were indicated to be advantageous or disadvantageous to various types of equipment, oil burners of the steam-turbine-driven type were finally selected. The principal factors in-

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[1] General Manager, W. B. Conkey Company. Mr. Lewis has had experience in various phases of organizing, management, manufacturing, selling, and advertising. For five years he was associated with General Motors as an executive of its subsidiary, the Harrison Radiator Corporation. In 1920 he organized a selling company in Detroit to handle automobile equipment and after selling his interests in this joined the W. B. Conkey Company.

Presented at a meeting of the Metropolitan Section, A.S.M.E., New York, N. Y., April 4, 1930, sponsored by the Printing Industries Division.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

fluencing their selection were, first, the elimination of coal dust and soot which contributed to the spoilage losses in all departments, and, second, the availability of oil and low cost of delivery, due to our location near some of the world's largest refineries.

The result of this installation has already shown a reduction of 51 per cent in labor costs, an increase of 30 per cent in efficiency, with an increase of fuel cost of 15 per cent. The reduction in spoilage losses by the elimination of coal is an indeterminable factor.

The heating of the plant was also made the subject of an engineering study. The former method of heating by an indirect system, with open recirculation from a central heating plant, was changed to the use of unit heaters of the high-velocity type, because of the large open areas existing in the plant, which is of sawtooth roof construction and all on one floor.

The unit-heater system shows an increase in efficiency over the central heating plant of approximately 43 per cent. Figuring interest on the investment of unit heaters, depreciation, and maintenance, the change-over to the unit-heater method has resulted in a reduction of 21 per cent in heating costs.

After a careful study of the composing room, the metal-casting department was removed from the main composing room to a small foundry room built on an outside wall with special attention given to ventilation, in order to remove heat and undesirable fumes and to bring about a better arrangement of the composing-room equipment. Additional steel cabinets were purchased, together with several thousand new galleys. Two new Intertype machines were installed. Special departments were created within the composing room where the standing type and plates of certain large customers were consolidated in order further to facilitate the handling of the work of these customers. As a result of these changes, the realignment of equipment, etc., indirect labor in this department was reduced 27 per cent.

The pressroom next came in for attention. The first move was to call upon the master mechanic, the superintendent, and the pressroom foreman for a report upon the condition of each press. Men from the engineering and service departments of the various press manufacturers were called in, and the presses were put in condition to produce the highest quality of work.

A study of pressroom operations and production figures disclosed inefficiency due to improper scheduling, loss of time in make-ready, and excessive spoilage losses.

A system of schedule planning was worked out which gave the pressroom foreman advance information as to what jobs were to be run next and what presses were to be employed. This relieved the foreman of detail and responsibility and permitted him to watch production of quality work more closely.

It was found in this study that the principal loss of time in the pressroom was in the make-ready. This was due to the fact that the ordinary proofing press in use did not disclose minor imperfections in plates and type pages. These were invariably disclosed after the job was made ready for the press, which caused loss of time in returning the plates to the foundry for repair and for type repair on the presses.

To overcome these details and to eliminate this loss of time, a pre-make-ready system was established whereby all plates and type pages were tested on precision proof presses as well as through the use of testing gages, and all necessary readjustments were made before plates and type pages were delivered to the pressroom. In practice this pre-make-ready system worked out exactly as planned. The loss of time in make-ready was reduced to a minimum, spoilage losses were eliminated to a very great degree, production was materially increased, and a higher quality of work resulted.

Needless to say the subjects of ventilation, temperature, and humidity control in the pressroom also received attention with very gratifying results.

Following the changes which were made in the pressroom, reorganization of the bindery was undertaken.

For the benefit of some who may not be familiar with the conditions existing in the printing business, the fact should be pointed out that of all the departments in the modern printing plant, the bindery department probably shows the greatest fluctuation on the production chart. Therefore for this reason and because of the fact that there are so many different operations, the reorganization of the methods, equipment, and personnel employed in the bindery called for greater attention than practically any other department of the company. Because of all these factors a careful study of all the ramifications was made. There were the operations of folding, gathering, sewing, trimming, gluing, rounding and backing, forwarding, case-making, stamping and embossing, casing-in, etc., to be considered.

It might be said that a finished book is only as good as the folding. Therefore, the folding department is a very important department in the manufacture of books. Inaccuracies in the folding of otherwise perfectly printed sheets cause a high percentage of rejections in the final inspection. Because of this, the folding department came in for special consideration. All of the folding equipment was very carefully checked. Poor equipment was eliminated. Improper layout, lack of intelligent supervision, and careless inspection were entirely done away with. Consequently, the resulting high spoilage losses and the high percentage of rejections which were discovered after the books had passed through succeeding operations were very greatly reduced.

Equipment in this department was brought up to a high degree of efficiency by the repair and adjustment of certain pieces of equipment, the removal of old models, and their replacement by new folding machines.

A new system of scheduling was worked out which coordinated with the pressroom schedules to meet the requirements of particular conditions with respect to sizes of sheets handled by the presses and the imposition. In conjunction with the operation by schedules and the realignment of equipment, a system of inspection of the folded signatures was inaugurated, which reduced spoilage 37 per cent and substantially reduced the rejection of finished books for inaccuracies in folding in the final inspection.

The personnel of the engineering department was increased in order to give study to the development of mechanical means for the displacement of certain hand operations. As an illustration, an automatic head-banding device was developed and attached to a forwarding machine, which makes and attaches either linen or silk head bands with a remarkable degree of efficiency. This improvement made possible the elimination of two hand workers.

An automatic end-sheet marking device was perfected and attached to a gathering machine. This made it possible to eliminate two girls.

Special equipment was designed which increased the efficiency of the tipping machines approximately 30 per cent.

Mechanical improvements were developed by the engineers in the hook-up of stitching heads to gathering machines. This also resulted in a marked increase in the efficiency of the combination.

Belt conveyors were developed to eliminate trucking and the handling of material within certain departments of the bindery.

Rounding and backing machines which operated from a line-shaft at fixed speeds were brought into better alignment in the

production scheme and equipped with individual motors with speed controls. As a result the cost of power for operating these machines was reduced 10 per cent and the production increased 13 per cent.

As will be noted, the natural flow of finished material is from the bindery to the inspection department. This department was also analyzed, with the result that it was relocated to provide the most favorable natural light. Special artificial light was also added. The department was entirely reorganized. Tables of uniform height, length, and width were installed with wide aisles for the free movement of finished books.

The plan of inspection was improved. All of these changes resulted in better inspection with increased output and a reduction in the criticism of customers regarding imperfect books.

Inasmuch as it is a practice in the industry to produce a great number of books for a publisher and then hold these books in storage subject to the publisher's order, the question of book storage and the proper storage and shipping facilities is of vital importance. This company carries an enormous quantity of books on hand for its customers. Shipment of these books is subject to the customer's order, and the quantities range from a single book to a carload shipment.

Because of the fact that this department contained merchandise actually owned by the customer, it required intensive engineering study in order to eliminate losses due to improper handling of finished books.

Formerly these finished books were stored in four separate rooms, which resulted in excessive handling cost and poor supervision in storing and handling. In changing the general layout of various departments, a single commodious book storeroom was created, providing accurate direct supervision of the work of storing and handling these books and filling orders for them.

Wooden shelving was discarded for steel shelving of the latest type. Improvements in methods of storing and handling were worked out to insure protection of the books from dirt and moisture and from damage in handling. Books owned by the various customers were consolidated as to location on shelf and platform storage, and a perpetual inventory system was established, which gave the stock keeper the balances on hand and their location at a glance. These improvements resulted in a reduction of labor in this department, greater speed and accuracy in filling orders, and assured a perfect condition of the book stock at all times.

In conjunction with the reorganization and rearrangement of the book-stock department, similar changes were necessary in the shipping department. This department was gradually enlarged. Sidetracks to the plant were rearranged permitting the erection of longer and wider loading platforms, with both platforms and trucks brought under a roof, assuring complete protection from the elements to workers as well as to raw materials and finished products.

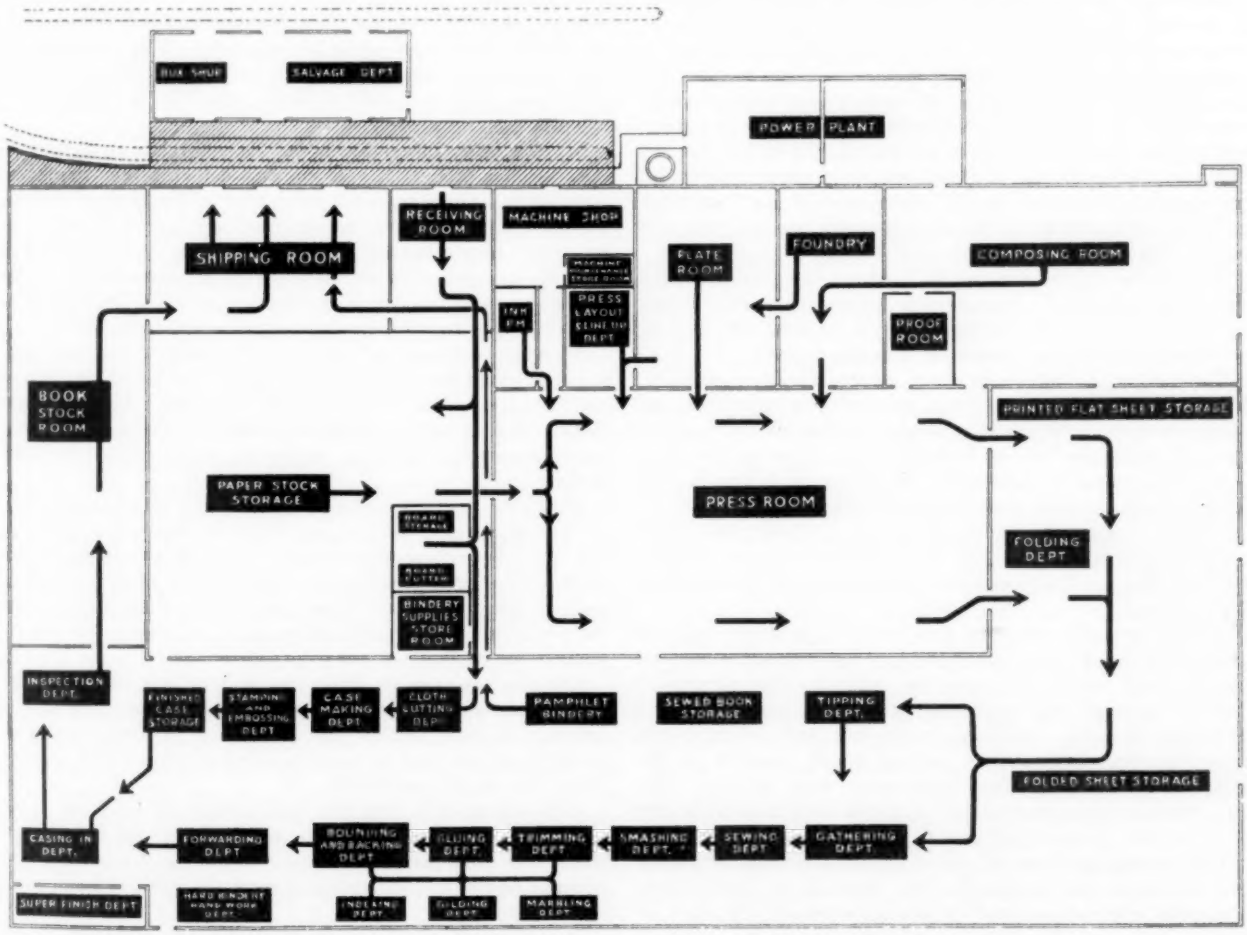


FIG. 1 PRODUCTION FLOW IN THE PLANT OF THE W. B. CONKEY COMPANY, HAMMOND, IND.

Additional material-handling equipment was provided, particularly lift trucks. Loading and unloading of freight cars was speeded up. Demurrage charges were eliminated. Spoilage losses caused by the elements were cut down. The time consumed in loading and unloading operations was materially reduced.

With the present methods employed, a carload of 40,000 lb. of paper on skids is now taken from the car and delivered to the floor of the paper stock room by two men in 24 minutes. This is a very substantial reduction in the time previously required for this operation.

Throughout the rearrangement of the plant and the changing of methods, the engineers were continually confronted with customers' problems which are peculiar to this business. For instance, many large contracts which involve type composition, electrotyping, presswork, and binding specify that only a portion of the total quantity be bound at a given time—the unbound portion to be held in storage to await further binding orders.

The former method of handling this problem was to store the flat sheets unfolded. This resulted in excessive spoilage losses in handling. A change was made in this method in the important respect that the entire quantity was folded, tied in bundles and stored in the production line between the folding department and the next operation. In the enlargement of the floor space and the rearrangement of the manufacturing, storage space for this purpose had previously been provided for.

This change in the method of handling the printed sheets resulted in a decided improvement in the quality of the finished books, better service to the customers, a material reduction in spoilage losses, and the consequent lowering of costs.

The storing of customers' plates involved another problem. It is a decided advantage for a printer after completing an edition to be able to retain possession of the necessary plates for that particular job, as it enables him to secure the next order with less sales resistance. These plates belong to the customer and naturally must be kept in good condition.

Prior to the rearrangement of the plant, these plates were stored in two rooms separated by a distance of approximately 400 ft. This resulted in excessive trucking, record keeping, and supervision.

After thoroughly studying this problem, a single room of ample area and of fireproof construction was located between the foundry and the layout room and adjoining the pressroom. The plate storage was consolidated in this room, which provided additional shelving, handling equipment, and an improved record-keeping system. The savings which resulted in the expense of operating this department were obvious. The importance of these savings can be gaged when it is considered that the cost of this department is purely a matter of overhead.

If a printing plant can be said to employ the use of perishable raw material, that perishable raw material is paper stock. Unprinted paper stock must be handled carefully. It must be stored carefully. Humidity conditions must be watched. Useless handling simply results in excessive costs. With these things in mind, the method of handling paper stock was also completely changed.

Formerly this paper stock was stored in two separate rooms, one of which was located at a point remote from the pressroom, which naturally necessitated excessive trucking and handling. In the rearrangement and enlargement of the various departments the paper stock room was relocated in a single room immediately adjoining the pressroom.

The practice of storing the stock as delivered from the mill—namely, in bundles, cases, and on skids—was abandoned. Instead, the paper is laid out flat, ready for the presses, in a room adjacent to the pressroom which is adjusted to predetermined temperatures. As a result, the paper comes to the pressroom free from wrinkles, properly seasoned, with expansion and contraction due to differences in temperature eliminated in so far as possible.

An important change was made in connection with the handling of waste paper, which runs into considerable tonnage in the form of shavings, from the trimmers and from other sources. The waste paper or salvage room formerly occupied an area of approximately 3000 sq. ft. in the main plant and was so located as to require trucking of the baled paper through two or three departments to the loading platform for shipment.

The location of this room also constituted a serious interference with any plan for a straight-line flow of production. In the general plan of improvements a new building was erected to house this department located on the side tracks serving the main building. Shavings are now carried to this department through pipes by blast fan from the trimmers and after baling are loaded directly into cars for shipment. The relocation of this department was an important factor in working out the production plan, and incidentally it permitted a reduction of two people in this department.

In the foregoing there have been discussed only such steps in the scheme of production engineering which already have proved themselves. There are other steps now in the process of completion. To discuss the results that will accrue from these would be only to hazard a guess. However, it is certain that with the completion of the manufacturing rearrangement in all its various ramifications, as has been outlined in the foregoing, there is under way the development of a real technique.

All work is being analyzed into elementary operations and accurate production standards are being established, from time and motion study, as a basis for wage incentives. More accurate costing is being set up, budgetary control is being established, and improvements are being made in all of the company's record systems.

A very casual study of the floor plan of our plant, upon which the flow of material and the progressive operations are indicated, will show the comparative simplicity of what a well-engineered production scheme means to the management of an institution such as this. However, it has possibilities of accomplishment far beyond merely the elimination of a few people, the betterment of the product, and the reduction of costs.

The greatest possible thing that can be said regarding the application of sound production-engineering principles in the printing business is that the application of these principles provides as good and as sound a merchandising factor as anything that can be considered.

It is fundamental that men and institutions have two basic requirements placed upon them regardless of the industry of which they are a part. These basic requirements are the ability to make money and the ability to serve the world at large while making money.

Regardless of all the other reasons as to why one should improve the quality of his work and his methods of operations, this one important factor remains—the man who pays for doing a certain piece of work is entitled to receive the very best for his money that it is possible for him to get. It is an obligation to see that he gets it. One can make money by giving it to him only in relation to the manner and to the extent to which it is made known to him that one is in a position to do this. By doing this it is better for the individuals who are a part of the producing organization. Therefore, the finest thing that can be said for the application of correct production-engineering principles in the printing industry is that it is a factor which can be very definitely merchandised to the business world as a whole.

The Munder System for Paper Selection

By NORMAN T. A. MUNDER,[1] BALTIMORE, MD.

There are many makers of paper, and each one sends out sample books. These books are generally addressed to some individual in a printing or advertising house and become his property. The Munder system for paper selection provides a cabinet containing the paper-sample books of 54 paper makers. These books, over 400 in number, are indexed by uses, qualities, and prices, and provide an easy reference for all in an office who are interested in the selection of paper for various uses.

THERE is hardly a more important or a more perplexing question, hour by hour, than finding just the right paper for the purpose, in texture, color, price, and other required characteristics, together with the name of manufacturer and merchant. The Munder system for paper selection meets this problem with minimum effort and maximum speed. The author has built this system after a continuous experience of over forty years.

The most popular papers for advertising purposes are book and cover papers; provision has been made principally for this kind of paper, and from paper makers offering mill brands with national distribution. Such papers, made in large quantities to supply the whole country, must have the best quality with fair prices. While this receptacle of the Munder system holds over 400 sample books representing 54 paper makers, it will also hold many others; furthermore, papers of all kinds can be substituted for any items not desired.

In nearly all offices the very useful sample books become the property of the individual who happens to receive them. With the Munder system these books become official ones and are filed for the use of the entire organization. They are labeled, and the one using them must replace them in the numbered compartment to which they have been assigned.

Offices having installed this sytem can readily find the latest styles in paper. A buyer asking for a certain kind of paper can be handed that very paper at once and not a substitute.

Two books a day, on the average, are received in the office of the user of paper, either through the postman or a salesman, and it takes two minutes to file a book; the index cards, revised twice a year, on which are printed all of the nationally advertised mill brands, offering a quick and complete aid. This means that an average of four minutes a day keeps an organization up to the hour in paper styles. The advertising expert or printer is expected to be up in paper styles, just as all other lines of business are expected to be.

The Munder system places before the user one receptacle. Its many compartments in four rows hold over 400 sample books of mill brands with a national distribution.

In another series of compartments just beneath are two rows that will hold 50 sets of dummy sheets. While these two bottom rows are planned for dummy sheets and finely printed specimens of all kinds in large strong envelopes, they can be used for more elegant and larger sample books if desired. These shelves are 13½ in. in height, 22 in. deep, and of adjustable width. There are two cupboards on the upper sides of the cabinet in which shelves can be placed. These cupboards are 9 in. wide, 17 in. deep, and 36 in. in height.

This is a national system, serving equally well for any part of the United States. Alphabetical indexes, revised and published in January and July, make possible the securing of any one of the books in from six to eight seconds. One index is for cover papers, being a complete list, and a second index has a complete list of book papers. The makers' and agents' names appear with each paper.

Another extra feature of the Munder system is the book paper chart (a cover paper chart may be developed later) revised and published quarterly, size 24 × 27 in., to be posted up for general office reference or placed under the glass top of a desk. This chart places in a group, graphically, nearly 300 book papers, in seven divisions: Enamel, Dull Enamel, Antique, English Finish, Machine Finish, Super, and Offset, and each class is placed under relative price headings, from 8 cents to 70 cents per pound.

An interesting code locates without sample books the paper with the characteristics needed. Thus: D, "deckle;" C, "more than two colors;" H, "also heavy weight;" S, "two sizes or more:" W, "wove;" R, "rib;" P, "plate finish;" HM, "handmade finish;" M, "medium finish;" L, "laid;" SP, "special finish;" Env., "envelopes to match;" etc. After the paper has been considered by this means, one turns to the filing cabinet and finds in from six to eight seconds the very paper in book form, full of demonstrations of what the paper will accomplish. Several papers of a similar nature can be compared and the best selected.

There is no system similar to this one for paper education. Those just coming into the printing, paper, and advertising business can select seven different classes of paper found in the sample books of the cabinet. When these papers are compared, the real difference in the seven kinds, and what can be accomplished on each one, can be seen readily. This can be done in a few moments, and can be repeated, using the different books until the beginner really knows paper; it would take years in an ordinary experience. There are many new processes today, all of which are represented in these hundreds of interesting books.

The Munder system develops executives, and places them in a position to become most efficient salesmen for printing.

The receptacle, or filing device of the Munder system, is ornamental and can be made in color to match the other furniture. This cabinet can be delivered unstained or jet black for decoration along modernistic lines. In size it is 36 in. wide, 26 in. deep, and 81 in. high. A smaller size receptacle will be made for smaller plants.

The paper makers are constantly planning and are having made by the best printers in the country fine sample books which show the trend of design in direct mail advertising. These sample books are mailed to a special list of printers and advertising organizations, from ten to thirty thousand at a time. A limited number of these books are retained, but not many. The books are so valuable that they should be properly kept and frequently referred to for inspiration and real guidance in making appropriate things. These original copies should be placed in the Munder

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[1] President, Norman T. A. Munder & Co. Mr. Munder has been an employing printer since 1887 and has grown up with the American paper-making, printing, and engraving industries. He made the first large edition, two carloads, of sample books for the Mittineague Paper Company, now the Strathmore Paper Company, in 1906; a sample book still in use. The Munder organization has helped to develop important papers and has made sample books for nearly all the great paper makers.

Contributed by the Printing Industries Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

system and not allowed to lie around and be abused, perhaps lost. Sometimes these books are given to a customer, only to be discarded. When one of these books is wanted, and cannot be found, there is small chance for the use of that paper; it might be the one most needed. It is not extravagent to say that in these 400 books there may be found thousands of fine ideas in types, borders, and decoration, each a real inspiration.

As soon as a sample book is found offering a suitable paper, a dummy is planned and dummy sheets are needed. The Munder system provides strong dummy envelopes, 14 × 24 in., each of which is numbered, and belongs in its own numbered compartment. These envelopes hold full sheets, 25 × 38 in., folded twice, or 20 × 26 in. folded once; most dummy sheets are too small to be useful. Interesting dummies can be made on the spot and loose sheets can be passed to the presses for immediate experimental work. Say that the question arises, "Have we dummy sheets of 'Grandee'?" On the index opposite "Grandee" appears a second number just below the first one—the upper number refers to the sample book compartment, the lower number, for example No. 133, would mean that there were dummy sheets for "Grandee" in envelope No. 133. Paper salesmen supplying these sheets now have a better way to sell.

PI-52-3

Printing-Plant Operation Without Alibis; Is It Possible?

By HADAR ORTMAN,[1] DES MOINES, IOWA

The author describes printing-plant operation as "the industry of alibis," and he asserts that it is easy to designate duties and to prepare specifications and instructions so that responsibility may be placed where it belongs and mistakes may be properly traced and their repetition prevented. He summarizes the principles of successful management and operation under eight heads.

SOME time ago while I was in Chicago I overheard two paper salesmen making fun of some simple-minded newspaper publishers in Iowa who insisted in putting on their paper orders "static-free paper." Not long after my return to Des Moines I found the result of our chemist's analysis on an ink cure which, according to letters of recommendation, was successfully used by prominent printers in New York and Chicago. His finding was that it contained a very ordinary ink base plus a certain amount of organic oil added solely for the purpose of mystifying the product; it did not contribute additional qualities to the compound. However, the ink cure was selling for five times that of the useful ink base.

Conversations with printers in other parts of the country convince me that the problems we have in Iowa are exactly the same as you have here in New York. So let us try to agree on a common basis for the later discussion.

The purpose of the printing plant is to produce as near perfect printing as possible at the lowest possible cost. This, you might say, is an axiom of all production managers, but it does need repetition as such. However, the relative importance of the cost and quality factors varies somewhat for different jobs.

The next step in our reasoning is that perfect printing is produced by transfer of ink from a subject plate to a sheet of paper. As the thickness of paper is being measured in thousandths of an inch, the press operation is necessarily such that all factors involved have to be expressed in thousandths of an inch and fractions thereof rather than in inches.

Imperfect bed, imperfect plates, imperfect cylinders, imperfect packing, imperfect rollers and roller setting, imperfect ink, imperfect mechanical motions of the press, imperfections in the sheet—none of these, of course, can contribute to perfect printing.

The struggle against all these imperfections is incorporated in a series of operations which is called make-ready. It can readily be seen that it covers a multitude of sins, and if not intelligently performed introduces new imperfections with additional need for make-ready, and so on.

A temporary condition with apparently satisfactory running result is finally obtained. But what happens without all the working conditions in perfect balance? Through wear and knocks new imperfections are caused, making it necessary to stop a $1 to $50 an hour press to make an approximate correction of some kind which will take care of the situation until the next delay. The more imperfect the printing conditions and the higher the speed, the more apparent the evil results are going to be, as vibration of the machine accentuates the errors, and vice versa. And, furthermore, while a run is being made without perfect equilibrium, even though with repeated corrections the printing results might be acceptable, the press parts are steadily wearing out, as the machine was designed and built for certain balanced conditions.

With machine speeds varying between 1000 and 100,000 an hour, pile after pile of printed sheets are manufactured, each varying in degree of perfection. One peculiarity in our industry is that if a sheet is printed imperfect there is no corrective operation available that can make it right. It is either accepted or scrapped. Imperfections of the kind discussed have to be discovered by careful, almost microscopic, examination of delivered sheets. With the tremendous speed frequently involved and the high cost of idle machine time due to delays, it is quite evident that preventive measures are extremely important, and, furthermore, sufficient checking of delivered sheets must be done to prevent thousands of imperfect sheets going through.

Some time ago the web on one of our presses was repeatedly broken off, causing an unusual amount of delays. The reason was found to be an unevenness in the thickness of the paper. At certain spots it was as high as 25 per cent above standard.

Complaints were received from the inspector to the effect that certain two-color rotary pages were offsetting, not trapping, and of poor quality. A large amount of time was spent in trying to correct it. It was found that, unknown to the manager, the pressman was using color ink purchased for flat-bed presses.

We had an order to produce a print job on oilcloth. Uncertain about how it should be done, the foreman and job pressman experimented for two months to find the correct ink. Finally the job was run, but because of imperfect ink nearly one-third of the job was rejected. Less than one day's work on the part of our chemist resulted in an ink which produced perfect results.

On two of our two-color Miehles it was necessary to change rollers every two or three days. The printing at times was perfect, and at other times it would slur and show other deficiencies. It was found that not only had the wrong composition been ordered, but also that rollers had been accepted which were green.

On one of our Babcock presses it seemed at one time impossible to maintain register. Local temperature and humidity conditions around the press, the condition of the paper, cylinder, bed, and so on were investigated, but no explanation was found. Finally it was discovered that the cylinder bearing was worn, causing this condition.

One form was worn out before we had obtained one-fourth of a run. An investigation showed that the foundry had rushed

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Presented at a meeting, April 4, 1930, New York, N. Y., of the Printing Industries Division, American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

the production of plates; consequently it had delivered plates with soft shells.

On a duplicate run one subject was produced with two different screens, and the cuts had been made by the same engraver. Another was reproduced by two engravers with the same screen. In each case one of the reproductions was very superior to the other.

A pressman was complaining that the speed of the motor for his press varied. It was found that the voltage of our intake lines varied 10 per cent.

I could go on for hours telling you about past experiences of this kind, and so could any of you. I am not ashamed to tell them, for they are common, daily occurrences in most printing plants in the country.

And then the average production manager goes down to Pressman Jones and says, "Bill, your run last month was 10 per cent below standard speed."

"Well," answers Jones, "the paper stretched, the rollers weren't any good," and so forth and so on.

And then what does the production manager have to say? The average production manager just does not know for sure whether he supplied Bill with uniform paper, or good plates, or suitable rollers. Consequently, how can he honestly blame Bill for the outcome of the run? In order to free his own conscience he might insist on blaming Bill for the result, but Bill might rightly think that his boss is unfair. Perhaps the production manager knows that the materials and supplies and even the press were perfect, and perhaps the poor result was due to improper roller setting or make-ready, but is he sure that Bill was properly taught how to master each step in the press operation or that Bill had the time to perform them as instructed? Of course, you all agree that these are also responsibilities of the production manager.

While our production manager is looking over the printed sheet with offset here, a broken letter there, and a mud picture representing the pretty garden spot, the red being out of register and causing an old-fashioned illumination around the nose of the semi-nude hosiery girl, he might clear his conscience by drawing some of these conclusions:

1 The art department certainly did not get a good photograph that time.

2 It certainly seems impossible to get a real, honest-to-goodness pressman any more.

3 I wish that the electrotyper, the roller-maker, the paper-maker, the ink-maker, the engraver, the pressmaker, and the smut-roll manufacturer would learn their business.

Perhaps at this time the quack salesman comes along and pictures the glories of his paper without static, his press without evils, and his all-cure ink medicine. We grab them, and for a few months we are enthusiastically insisting that our troubles are all over, until we finally have to classify the last savior with the engraver and the rest of the evil-makers.

And when we print-shop managers get together to discuss means and ways to improve the industry, we start the same story in chorus: "If only the artist, the paper-maker, the ink-maker, the roller-maker, the electrotyper, engraver, and the pressman would learn their business." Very little is being said about: "What can we do to be sure that the materials and supplies are exactly what we want? What can we do to get our own organization to use these machines, materials, and supplies intelligently and correctly?"

Because of the multitude of materials and operations involved in the series of crafts, the final result of which is the printed sheet, and because of the extreme accuracy required by each—really beyond the working capacity of the average brain employed—the printing industry is a virgin field for quacks and magicians and offers wonderful opportunities for alibis, throwing the blame for imperfect sheets back, successively, to operations preceding the press operation. Even though I agree that many of those alibis are well founded, I still maintain that we printing-plant managers and others of our profession are primarily responsible for imperfection in the printed sheet.

If we all insisted on uniform and suitable materials, the vendors would be forced to supply them, because it can be done in most cases. If we are checking the quality of our supplies and materials before they are sent down to the pressman to be used, the cause of a large part of his alibis has been eliminated. If we utilize sound organization principles in our plant covering the division of labor, employment, training, maintenance, controls of various kinds, we have eliminated a lot of the causes for the alibis which we now are handing out to customers or that we hear daily from our subordinates.

A prominent electrotyper who recognized the evils of poor engraving for his profession decided to head it off by employing the best engraver in town, with the instructions to correct the engravings before they were sent to the electrotyping operator, or whenever possible to reject them and insist on getting new cuts. Incidentally, he told me that the temptations were too great in doing this without the customary faking methods, and when caught the engraver said that he could not see what the pressmen would do if he made such perfect engravings. But the electrotyper's idea, I think, was good, and I believe if we would apply the same thought to all jobs in relation to printing, we would eliminate a large part of the print-shop alibis.

In purchasing blocks for some of our presses we specified that they should be within one-half of one-thousandth accuracy. The block manufacturer accepted our requirements and supplied us with the desired number within the specified accuracy. In accepting the order the manufacturer said that most of the printing plants did not have such requirements, and if there were any of the blocks in the batch that were not acceptable to us, he could easily get rid of them.

Discussing certain features of make-ready with a precision-tool manufacturer, certain qualities of his tools were criticized. Defending his position, he stated that most printing plants were not able to handle tools with such precision, and that he, in order to commercialize his product, had to build them in their present form. These examples will serve to illustrate my point that real progress could be made if we all increased our demands on the auxiliary industries.

Let me now describe to you some of the things that we have tried to do in our plant for the purpose of eliminating causes for alibis. Let me first state that I do not in any way want to intimate that we have gone so much further than all other printers—perhaps not as far as the majority—but my instructions were to talk about the application, and that is what I want to do. The time is short, and it would not be possible to mention even all phases of the work. My purpose is to discuss some of the things we have done to eliminate causes for alibis, which will illustrate some conclusions which I shall draw at the end of the discussion.

Let us start with reviewing the procedures concerning engravings. You will probably think by now that I have some grudge against the engravers. I have none. I do not think they are to blame for using the old Washington proof press which last year celebrated its centennial birthday, and for smearing it up with ink ten times as costly as we can afford to pay. I think that we ourselves are to blame for not insisting on better engravings and honest proofs.

We know our pressroom conditions. This means that we ought to specify to our engravers the screen, the depth, and the type of retouching that we need. This is being done by our

organization through a purchase order. Furthermore, when an engraving comes in we have an engraver in our plant who tests the cut by pulling a proof on an honest proof press and who examines the cut for depth, etch, and so on. If it is not satisfactory, we reject it. If we would all do this, would you not think that the Washington press and engravers' special ink would be two items of the past?

Of course, the engraver comes back every so often and says, "If I could only get good photographs to make good cuts from," etc. We are trying to head off this alibi by systematic instruction to our art department, which places orders for engravings in the various phases of the printing problems.

One of the most effective ways of doing this is, we have found, by having monthly meetings. As soon as the first copy of an issue comes off the press, we call in the art director, the engraver, the plate inspector, the pressroom superintendent, press foreman, and pressman. Each page of the book is criticized. If necessary the original photographs and engravings or the plate proofs are brought in to enable us to reach a decision. These meetings give every one concerned an understanding of the problem of the other fellow, and, particularly, the art director is supplied with the necessary knowledge to start the printing routine correctly when he places orders for engraving.

We thoroughly realize that imperfection in a form locked up in the composing room is transmitted to the printing plate, as electrotyping really is a duplicating process. The logical thing to do, consequently, is to be sure that all types used, whether for machine or hand composition, are uniformly type high and otherwise perfect. This is easily accomplished by daily inspection, aided by the Hacker gage, which is a part of the equipment in our so-called plate-preparation department.

The principles of the procedure in handling purchased electrotypes are fundamentally the same with engravings, but of course the inspection is made by another man thoroughly versed with electrotyping. Paralleling what I said about engravings, we specify when we order electrotypes if we want wax or lead mold and whether nickel plated or not.

Let us now for a moment review what we have done to eliminate alibis concerning engravings and electrotypes:

1 We accept responsibility for specifying to our engraver and electrotyper the standards desired for certain variable qualities in their products so as to fit our printing-plant conditions. This eliminates alibis about mistakes made because of lack of knowledge of our problems.

2 We are expanding efforts on perfecting the originals submitted to engravers and electrotypers so as to eliminate alibis on their part that the originals were poor.

3 We have developed specialists in our plant who are able to inspect intelligently engravings and electrotypes received. In the case of engravings this inspection eliminates alibis on the part of the electrotyper regarding the originals. In the case of the electrotypes it eliminates alibis on the part of the pressman of imperfect printing due to imperfect plates.

Let me illustrate what we have done to eliminate alibis concerning run-down or inefficient equipment. Each month before a run is started the press must be carefully checked by a skilled mechanic. In order to be sure that this is done correctly, we have provided him with a checking sheet showing all the parts that are to be inspected. A copy of the same check sheet is hanging near the press during the run so that the pressman can check items which will need attention according to his observations of the press. The pressman's check sheet is then given to the mechanic at the time of the monthly inspection. You notice here again that some of the same principles are used as were given in the preceding paragraphs in regard to engravings and electrotypes, as follows:

1 We have a specialist who can more ably, and at a saving of time, attend to the mechanical features of the press.

2 We have enlisted the cooperation of the pressman and have also placed a certain share of the responsibility on him for the maintenance of the machine.

3 We have systematized this work by making it a regular routine which prevents oversight of detail and conserves time.

The most important feature of paper control from the standpoint of printing is without doubt the question of uniform quality. When a paper has been decided upon for a certain purpose, all other factors involved have to be adapted to this paper. As publishers of magazines we are naturally using the same kind of paper for a long period of time without changing. Because of the volume and the speed requirements, it is naturally of extraordinary importance to us to get paper of uniform quality.

Our chemist, in cooperation with the purchasing and manufacturing departments, has agreed upon the standards which should be maintained for each of these qualities. The chemist is equipped, in his laboratory, with instruments so that he can measure these qualities. The standards so agreed upon with the organization have also been accepted by the paper mill with the understanding that all paper that is delivered which is not in accordance with these standards shall be returned. There is nothing new about this, but let me in this connection stress that only qualities of importance to printing should be checked. Time can be and is often wasted by measuring qualities of no practical importance to the finished result. Naturally this testing is carried on as a definitely mapped-out routine with suitable forms for work sheet, test summaries, monthly reports, and so on. Here again we have applied the same principles:

1 A specialist who can intelligently check paper.

2 Standards for qualities which the pressman has agreed are acceptable for printing and which the paper mill agrees to meet.

3 A definite checking routine whereby we are reasonably sure that all paper delivered to the pressroom is of acceptable quality.

I said "reasonably" sure. It is of course realized that each sheet cannot be checked. But with the procedure as outlined, the alibis on the part of the pressmen, referring to quality of paper as a hindrance to production, have been greatly reduced.

Let me in this connection remind you that paper is a primary factor in the printing operation. A great number of factors have to be adjusted whenever paper stock is changed. I just want to mention such items as screen, body of ink, setting of ink fountain, packing, and so on.

In years past we had an illuminating experience. We were working with a paper mill to improve a certain grade of paper. Each month an improvement was made, while many of the secondary factors were maintained. Finally we woke up to the fact that, while the paper stock had been improved, the printing was not up to standard. It was found necessary to adjust, primarily, screen and ink, in order to again obtain printing of standard quality.

Ink and rollers are handled very much in the same way as paper. The large majority of qualities of these mentioned materials can be measured. Some, however, must be judged, but the more systematically this latter procedure is performed the better the results. Sometimes, for instance, high and low can be stipulated by means of samples which are kept in the laboratory and with which incoming shipments are compared.

How often have you complained to your paper-mill man because of paper stretching, and, consequently, poor register. And how often has he told you that humidity and temperature conditions in your pressroom are causing these troubles. And how often has your pressman told you that he could not obtain register, that he was delayed because of static, and so on.

We have met this problem by installing temperature and humidity control in both paper stockroom and pressroom. Furthermore, we have specified that paper must be stored under these controlled conditions for a certain length of time before it is used. It is also necessary to maintain control of temperature and humidity conditions in order to carry on the careful checking which we have previously discussed. Humidity affects the various qualities of paper, and accordingly it would not be fair to the paper mill to set up standards if temperature and humidity varied at the time the measurements were made. It is your task to specify to your paper mill that standards should be met under certain specific temperature and humidity conditions.

Another item along the same line is often neglected. Your pressman might be required to look at his color sheet under a certain artificial light. Your inspector has looked at it with an even north daylight. This is not fair. The pressman can properly say, "How can you expect me to produce a certain result which I cannot accurately judge?" We have made real efforts and progress to equalize light conditions for pressmen, foremen, and inspectors, in fairness to every one concerned. Along this same line, are you sure that all your color men have a normal visual conception of color? It is an easy task to find out.

All of you know that temperature, humidity, and light conditions are oftentimes causing alibis for poor printing results. We have found that through the installation referred to a large part of these excuses have been eliminated.

Here is one point I want to stress. Through our humidity and temperature control we control these conditions approximately eight months of the year. Because of the high cost of refrigeration equipment we have not felt justified in installing such equipment, but eight out of twelve months means that 66 per cent of the time we can maintain a uniform condition, and if you add to that the capacity of the apparatus to reduce to some extent humidity and temperature during the four summer months, I think it is fair to say that we control these conditions 75 to 80 per cent of the time. This, you must admit, is considerably better than no control at all.

In many print shops it is very common to hear the superintendent and the foreman tell you that they do not have time to follow up closely on the work, procedures, equipment, and results of their subordinates. In most cases their tale is true. The fault, therefore, of course, lies primarily with the upper management, as it either depends on the fact that too many duties have been assigned to them or that their work is being performed unsystematically. We have tried in our plant to eliminate these alibis by freeing our supervisors from some of the duties usually assigned to them and by assisting them in planning the day's work.

Equipment maintenance, for instance, is among the responsibilities of our building superintendent. Janitors are working under the direction of the building superintendent. Ink, rollers, and paper, in so far as storing, record keeping, issuing, quality checking, and so on, are duties handled by our chemist and the purchasing department.

Investigations of new equipment, layout of floors and working space, and construction of new procedures are all problems which are handled by our methods or our engineering department.

Under this type of organization, with functional division, it is of course necessary to establish intelligent cooperation between the line and the staff workers. It is definitely a duty of foremen and superintendent to bring to the attention of the department or individual concerned items needing correction or suggestions which will improve the operations of those allied functions.

It is equally important to discuss any change in procedures contemplated by a service department with the line supervisors concerned. Quite frequently valuable suggestions are made to the procedure by these supervisors, and it always furthers cooperation between the line and staff functions.

A common alibi on the part of the supervisor is that a rush order came in and he had to get paper cut, see about plates, call in men, and so forth. All this work is handled in our plant by our production department, so that when the order reaches the foremen it has been scheduled for a definite press, plates are in, paper and ink have been moved to the pressroom floor, and men have been assigned to the job.

It is very much easier for a competent office worker to lay out machine schedules, analyze the material requirements, and arrange the preliminaries for the running of a job than it would be for a foreman with all the interruptions which he has in the course of a day's work. I think these principles are quite well accepted by printing plants, even though there is a considerable difference in degree. In our particular case we are taking the attitude that the less of this work the foreman has to do the better off we are.

One item I have mentioned I would like to discuss further. Supervisors frequently are so loaded with routine work that they do not have the time to work out improved procedures for performing operations or to concentrate on elimination of causes for alibis rather than to just work out temporary relief for an unsatisfactory condition. Quite frequently, even though they might have time to do this work, they lack the necessary analytical ability. This I feel is one of the most fundamental weaknesses in most printing-plant organizations.

In the past discussion I have tried to enumerate some results from such an analysis. But this last point brings up the fundamental need in organizations to carry on such analysis constantly so as to obtain results of the kind I have previously indicated.

To me it is not essential that an individual analyst or a staff of functional engineers be employed for this purpose. The vital point is to have competent ability with sufficient time allowed for constructive thinking so as to obtain constantly permanent relief from imperfect conditions of various kinds as they are brought to surface. Consequently, it might be a line supervisor to whom this duty is assigned or it might be assigned to a separate staff function.

Quite frequently we criticize a common practice among pressmen to dope inks with secret fluids. It is true that very often the doping is effective. But is this not an admission that our purchasing department is asleep when it is buying improper ink? Furthermore, how can we expect the average pressman to do doping intelligently when it requires a thorough knowledge of chemistry. In our plant neither foremen nor workmen are allowed to dope inks. This is the privilege of our chemist only, and because of the close cooperation between our chemist and the purchasing department, it is a very rare occasion. The same holds true about color matching. Ink formulas are determined before a job reaches the press.

I do not need to say that these procedures are saving considerable amount of press time as, under the old procedures, the press was usually standing idle while the pressmen were playing with the mysteries of ink. When the duties of the pressman have been limited to such operations that he logically and economically can perform, then the next step is to train him thoroughly in the method of these operations. Whenever this is not done, we usually have almost as many methods in use as there are men. And still there is positively only one best way to do each operation. We complain of the fact that we cannot get trained pressmen, but whose fault is it, if not that of the pressroom management?

Personally, I feel that training is one of the greatest opportunities in pressroom management for obtaining improved results, and I cannot strongly enough urge production managers to give this matter very serious consideration.

Some other items concerning the workmen have been previously discussed. Such operations as washing rollers, cleaning blocks, and moving materials are often assigned to pressmen. These operations do not require a pressman's skill, for which he is paid. Consequently, it is not economical to assign such duties to him. Furthermore, the performance of such duties many times means that an expensive press is standing still instead of producing. It is of great importance to observe these principles:

1 To assign work in line with ability. (*a*) To assign specialists' duties to specialists. (*b*) To assign routine duties, which can be performed independent of the press operation, to others than pressmen.

2 To train each man thoroughly in the standard method of performing each operation.

Of course, the production manager in a good-sized printing plant needs his tools for seeing that all assignments are carried out in a satisfactory manner. This requires records of various kinds.

I am sure that all have had some sad experiences with your record controls. When your cost clerk finally brought in the statement for the month two weeks or so after its close, and you started to question your foreman regarding certain red figures, did you ever hear him reply, "I don't remember?"

Or did you ever find in analyzing causes through cost records that some items were combined to such an extent that no conclusion could be drawn? Or did you find sometimes that in the computation of a unit cost some additional variable element was injected because of improper selection of a factor on which to base your unit cost?

One of the most helpful reports we have in our plant is what we call our daily production record. Each morning this is placed on the desk of the production manager, superintendent, and foreman, and posted on the bulletin boards. This report shows the expected and actual production of each of the last three shifts and also the same accumulated figures for the month. It also shows allowed waste and actual waste for each shift and accumulative.

It is very easy to overburden your organization with records. But do they all assist you to make more money? I think that any control figure that is compiled must be isolated in scope so that a definite conclusion can be drawn from it. Furthermore, it must be of sufficient importance to warrant the work involved to compute it. And lastly, it must be computed without delay so that it is fit to serve as a current tool of management rather than a fact of historic interest.

Another point, of course, is that the figures must be presented to a person who is thoroughly competent to use them. Without a complete knowledge of how the printing operations are performed and the surrounding conditions, it is easy for foremen and workmen to present plausible but false alibis for a poor record showing. The men who handle the control must be able to verify the explanations given so as to place responsibility definitely for an unsatisfactory showing where it rightly belongs.

I have tried to give you the reasons why printing can be called "the industry of alibis." I have tried to describe different types of alibis. And finally I have demonstrated some of the methods we are urging in our plant to eliminate causes for alibis. Let me assure you that whatever we have accomplished along this line is just a modest beginning, and there are a number of great opportunities for further improvements awaiting us. But so far as we have gone, it has not only aided in straightening out friction and creating greater happiness in our organization, but it has also proved to be profitable from a monetary standpoint and has improved the quality of our printing considerably.

I am convinced that many of you will have objections to raise against some of the points of view I have expressed; perhaps the particular way we have organized our force would not suit your conditions. This might be true. Whatever has proved to be successful in our plant might not successfully be duplicated in yours. Imitation, anyway, is one of the greatest dangers in management.

The real purpose has been to illustrate some principles of vital importance to print-shop operation, the application of which will eliminate causes for alibis. Let me summarize these principles:

1 Develop absolute or relative standards for all materials and supplies which go into the printing operation, the physical conditions of the printing plant, the working parts of the machinery, and so on.

2 Develop definite procedures so that purchased materials and supplies are checked against these standards before they are used and so that physical conditions and machines are checked frequently enough to maintain standards.

3 Develop standard-practice instructions covering the method of performance of all work connected with the printing operations.

4 Narrow each task down in line with actual ability of the available personnel and place definite responsibility for certain defined results. This applies to supervisors, workmen, and technical staff.

5 Develop specialists whenever the scope of a technical task can warrant the employment of such a person. (*a*) If you do not have sufficient volume, contract for the services of some outside agency, either an independent professional or some one connected with a reliable vendor company. (*b*) The knowledge available to your organization should be broad enough to cover not only the problems of your own department, but also the details of the auxiliary industries so that you can intelligently check their contributions to the printed result and thoroughly understand the limitations of their industries.

6 Functionalize the simpler routine operations, such as material, handling, cleaning of presses and so on by relieving the highly skilled, high-priced technical men from these duties and assigning them to cheaper labor.

7 Train each job holder thoroughly in his tasks and instruct him in the principles of other tasks in so far as they affect the performance of his own.

8 Inaugurate controls that are definitely and actually usable in terms of completeness and promptness in showing whether assigned responsibilities have been fulfilled. This includes production follow-up, quality checking, and cost analysis.

Probably many are disappointed because I have not gone into any details as to how we actually do certain things, what instruments we use for measurements, what the different steps are in our make-ready procedure, how we set our rollers, and so on. To me these items are of minor importance in comparison with some of the principles which I have illustrated.

Well, now, what is the answer to the question we started out to discuss. Is it possible to operate a printing plant without alibis? Personally, I think that we have not yet reached such a stage of mechanical perfection in the printing industry that it is possible to operate our printing plant and interrelated plants entirely without alibis. Many factors employed in printing are still controlled by human judgment, and so long as this is the case, there will always be room for alibis.

However, I am thoroughly convinced that the largest part of the alibis that are now daily heard within our industry could be eliminated by removing the causes for them, or at least by narrowing the effects of allocated causes down within certain known limits.

PI-52-4

Paper and Printing

By E. O. REED,[1] DALTON, MASS.

Paper must have certain physical properties to be suitable for use with the different printing processes. Technical specifications for paper and paper testing have been developed to secure proper quality for a specific purpose, but it is not possible to standardize paper made by all mills on a few physical and chemical tests. Such factors as appearance, color, feel, finish, formation, or printability are distinctive mill characteristics. The qualities discussed by the author are paper finish, moisture content, and relationship to printing inks.

THE art of paper making is one of the most important and essential industries of the present day. Printing is frequently referred to as "the art preservative of all arts." This honor, however, should be shared with the art of paper making, since without paper the present-day printing could not exist. Paper is the chief raw material used by the printer and the lithographer.

The Chinese are generally credited with the introduction of the art of paper making from fibrous materials first reduced to the condition of pulp about A.D. 105. The art of paper making therefore predated the present printing art, the origin of which is generally accredited to Gutenburg of Mainz, Germany, in the fifteenth century.

The printing industry is now one of the world's largest and most essential industries, and in order to meet the paper requirements of the various printing processes in use today, the paper industry is required to furnish many different kinds of paper. Paper must possess certain physical qualities to be suitable for use with these different printing processes. It must also be of the proper quality to meet the service and permanence required, and which varies with the uses to which it is to be subjected.

During recent years considerable attention has been given to the development of technical specifications for paper and paper testing to control and measure its quality and probable durability. However, most attention has been directed to tests on paper for kind of fiber, physical tests for strength such as folding resistance, tensile strength, stretch, bursting strength, tear, and other physical characteristics in order to measure its strength, and to a limited extent to chemical properties and tests for probable life or permanence.

It is essential that large consumers of paper have a knowledge of the quality of paper as determined by such technical tests, and the use of specifications is advocated by paper manufacturers as a guide to the user in securing the proper quality of paper for any particular purpose and to furnish the paper manufacturers with definite information as to the requirements of the printer or his customer.

However, to the printer there are many other factors of more importance in his daily use of paper than the physical and chemical tests usually included in present-day paper specifications. Physical tests in specifications are frequently met by sacrificing other qualities important to the printer in securing satisfactory and artistic printing results. Paper mills have different standards and practices, and it would not be possible to standardize the paper made by all mills on a few physical and chemical tests, especially the fine papers including bonds, ledgers, writings, and high-grade printing papers. It is not possible to standardize the method of drying of high-grade papers, or such important factors of paper quality as general appearance, color, feel, finish, formation, or printability, which are all distinctive mill characteristics of the art of paper-making and important factors in the cost of manufacture. No reliable test methods have been developed for measuring these qualities, most of which it will not be possible to measure by technical tests.

It is not possible to determine definitely the quality of rags or pulp in a finished paper. Physical tests are the only aid, and because of the effect of various sizings and other factors on the results of these tests, they do not always furnish reliable information as to the quality of a paper.

A reference to the following qualities of paper should prove of interest to the printer or lithographer: (1) Paper finish, (2) moisture content of paper, (3) relationship of paper to printing inks.

Paper Finishing

Probably the most important characteristics in paper which are noted by every user of paper and especially the printer himself are color, finish, feel, and formation or "look through." With the use of dandy rolls attractive watermarks and laid-marks may be produced on the paper machine. High or special finishes on paper are produced by calendering or plating the paper after leaving the paper machines.

The finish of paper is a very essential feature to the printer, and the quality of his finished work depends upon the selection of paper which will give the best results with any particular character of printing. The finish on paper may be classified into three kinds, based on method of finishing: machine finish, supercalendered, and plater finished. The finish on machine-finished paper is produced by passing the paper through a stack of steel calender rolls at the end of the paper machine. Considerable variation in finish may be secured in machine finishing, from a rough or antique finish to a smooth or high finish. For ordinary printing from type or plates without halftones the low machine finish is satisfactory, and the highest machine finishes are suitable for coarse-screen halftones such as are used in newspapers and some magazines.

For the printing of fine-screened halftones it is necessary to secure a much higher finish or surface than can be produced with the calender stack on the end of the paper machine. Supercalendered paper is produced by passing the paper through calender stacks slightly moistened to aid in securing a smooth finish. A paper intended for supercalendered finishing is usually run through a few nips of the rolls at the machine, and is dampened before it is run on the reel. The supercalender is a stack of rolls, usually eight in number, but sometimes built with as many as sixteen. These rolls are alternately of iron and composition, although sometimes two composition rollers may be run together. Composition rolls are made of paper or cotton.

A high finish on paper and also attractive special finishes are

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Contributed by the Printing Industries Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

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produced on high-grade rag papers by plater finishing. The sheets of paper, after being dried either in loft or by air-drying equipment, are placed singly between copper or zinc plates or press boards, and a pile of these is passed several times through heavy rollers, great pressure being applied during the operation. The amount of polish or finish imparted by this plater finishing process can be varied considerably. With a high pressure and few rollings, the sheet of paper can be turned out having a fairly smooth surface and without a conspicuously shiny appearance. By employing great pressure and with repeated rolling, a much higher surface is attainable. If the plates are hot, a still higher finish is possible.

Special finishes, such as linen finish, are produced in plater finishing by inserting a piece of linen cloth or other material between the paper and the metal plate, and an impression is left in the paper after passing through the heavy iron rollers. These special finishes may also be produced by passing the paper between embossed steel rolls.

There is no available test at present which will satisfactorily measure the finish on paper. Practical printing tests are necessary to determine whether the finish on paper for halftone printing or map work is satisfactory.

Moisture Content of Paper

Considerable has been published relative to the effect of variations in moisture content of paper. Paper is a hygroscopic material, readily susceptible to variations in the atmospheric conditions to which it may be exposed. The effect on paper of changes in the relative humidity of the air is greater than that of temperature.

The moisture content of paper bears a direct relation to the relative humidity of the air to which it is exposed. For instance, printing paper exposed to a condition of 35 per cent relative humidity would contain a definite amount of moisture, probably between 3.5 and 4.5 per cent. Paper exposed to a condition of 20 per cent relative humidity would contain less moisture, and paper exposed to a condition of 50 per cent relative humidity would contain a greater amount of moisture. Therefore, if paper containing a certain percentage of moisture should be taken into a pressroom the relative humidity of which is considerably lower than would be required to maintain the moisture content of the paper itself, there would be a tendency for moisture to leave the paper; or if the humidity of the pressroom should be higher than would be required to maintain the normal moisture content of the paper itself, the paper would tend to take on moisture from the air. The results of this changing moisture content of paper, and the fact that paper in stacks will not adjust itself to the atmospheric conditions uniformly in the same length of time, cause curl, wrinkles, cockling, wavy edges, bulging centers, and changing dimensions of the sheet. Furthermore, the normal temperature and relative humidity indoors are not uniform and change from time to time.

In the production of newsprint and book papers in rolls it is possible for the paper manufacturers to maintain a definite moisture content of the paper within a variation of approximately $^1/_2$ to 1 per cent. With the use of water-resistance wrapping on roll paper there is practically no change in the moisture content of the paper from the time of manufacture until the roll is unwrapped by the printer for use, provided the roll is not exposed to excessive dampness or heat. However, unless the relative humidity of the pressroom is sufficient to maintain the moisture content of the paper, the moisture of the paper in the outer portion of the roll will change if the wrapper is removed previous to use. It is therefore advisable in pressrooms in which the relative humidity is not controlled not to remove the wrapper until the roll is placed on the printing press. In fact, the moisture content of paper will change so quickly that difficulty may be experienced while the paper is traveling the short distance through a high-speed web printing press provided considerable difference exists between the relative humidity of the air in the pressroom and the moisture content of the paper.

With cut ream paper it is more difficult for the paper manufacturer to maintain a uniform moisture content in paper. This can be done only by handling the paper after manufacture under controlled relative humidity conditions which will maintain in the paper the moisture content present when it was removed from the paper machine. Although ream paper may be wrapped or packed in boxes with waterproof case-lining paper, it is essential for best results that the printer store and handle the paper under controlled relative humidity conditions which will maintain the moisture content of the paper.

With high-grade papers which are tub-sized, it is more difficult for the manufacturer to produce finished paper with a definite moisture content. With loft-dried or air-dried paper it is necessary that the paper before finishing be exposed to humidified conditions which will allow the paper to absorb the desired moisture and that this moisture content be maintained throughout the processes of finishing, sorting, and packing.

The paper manufacturers are powerless to remedy difficulties experienced by the printer due to this moisture variation in paper without the cooperation of the printer. It would be advisable to install humidifying equipment in his warehouse, pressroom, and bindery, and for the printer to advise the paper manufacturers as to the condition under which he will handle his paper. Many plants have installed humidifying equipment, and it has been proved beneficial both as to quality of printing and as to economical production. From a study made in this connection it has been observed that relative humidities between 45 and 55 per cent are found most satisfactory. A condition as high as 60 per cent is used in some localities during the summer months if dehumidifying equipment is not used.

For certain types of work requiring exact registry it is essential that the paper be seasoned thoroughly in the pressroom by hanging the sheets in racks or by treating in paper-conditioning machines.

Relation of Paper to Printing Inks

Little has been published as to the relationship of paper to printing inks, and this subject is attracting the attention of manufacturers of printing papers at the present time. Considerable research has been conducted relative to the sizing quality of writing papers, and several methods are available for measuring the degree of sizing of paper as applied to water-base writing inks.

Bonds, ledgers, and writings which are tub-sized with glue or starch are resistant to absorption of oil-base printing inks, and for printing on such paper it is essential that there be used job or bond printing inks which dry chiefly by oxidation owing to their low oil-absorption quality. However, with newsprint and various types of book paper, including machine finish, supercalendered, and coated papers, the printing inks used contain little or no drier and dry chiefly by absorption.

From a study which has been made as to the relationship of paper to printing inks the following conclusions have been secured: (1) That methods proposed for measuring the degree of sizing of paper will furnish reliable information as to the relationship of writing inks to paper, but cannot be used to measure the ink resistance of paper to oil-base printing or mimeograph inks; (2) that rosin sizing does not render a paper resistant to oil-base inks; (3) that the printing inks used by the printer may be broadly divided into three classes: (*a*) inks which dry chiefly by absorption, (*b*) inks which dry both by absorption and oxida-

tion, (c) inks which dry chiefly on the surface of the paper by oxidation.

However, there is a need for a better technical understanding or standardization of printing inks before the paper manufacturer can satisfactorily control the ink-resistant quality of paper.

Although methods have been proposed for measuring the relationship of paper to printing inks, no standard test procedure has been adopted. A recent report on newsprint indicated that with this kind of paper a measure of the air permeability of the sheet would probably furnish a measure of the penetration of the printing ink. Newsprint inks dry almost entirely by absorption.

The research chemists of the paper industry are devoting considerable work to a study of this feature of paper which is of prime importance to the printer. However, the close cooperation of the printer from a technical standpoint will be required in the study of this problem, and all influencing factors should be carefully considered.

Permanence Standards for Printing and Writing Papers[1]

By B. W. SCRIBNER,[2] WASHINGTON, D. C.

Experience with printed and written records has shown the necessity of having adequate standards of permanency for selection of record papers. Sufficient technical knowledge is available for the formulation of such standards, and there is sufficient interest in their establishment to make such a project feasible. This paper outlines the available information on the permanence of papers and indicates how it may be applied to formulate definite technical specifications for permanence qualities. The history of paper making is traced to show its relation to the deterioration of papers, and the causes of deterioration as shown by the history of papers and by research are outlined. From this information is shown the necessity of dependence on performance and purity tests for selection of papers. The strength of paper and its purity, both cellulosic and non-cellulosic, are the important factors in its aging quality. A classification based on strength and purity is suggested, which places papers in the following four groups: (1) Papers of absolute permanence, (2) papers having a minimum life of 100 years, (3) papers having a minimum life of 50 years, (4) papers for temporary use.

THE question of permanence enters into all grades of printing and writing papers; even the lowest grades must have a certain degree of permanence to enable them to fulfil the service for which they are intended. There is, and has been for some time, an insistent demand for some standards by means of which a paper purchaser can have a reasonable assurance that the paper selected by him will have the necessary degree of life, and by which the manufacturer can be guided in making the paper.

The problem of fixing permanence standards is not a simple one, however, and no doubt this accounts for the present rather chaotic condition respecting such standards. It must be acknowledged that the technical and scientific knowledge desirable as the foundation of such an enterprise is not as complete as we would like to have it. However, this is generally true of most commodity standards. The establishment of them cannot await the development of complete knowledge of them; therefore standards for immediate use are usually set up, based on the best knowledge available, with the idea that they will be further modified as increased knowledge of their suitability is gained by their use and by research. Very little progress is made with any commodity standard until it is put into use; its usage stimulates study of it and is the most potent agent for its correction and development. It is believed there is sufficient knowledge available now to establish quite satisfactory technical standards for paper, including permanence. This discussion is for the purpose of outlining the information available and showing how it may be applied to permanence standardization.

Present Status of Permanence Standardization

The question of the permanence of paper has been a very live one ever since the introduction of wood-fiber papers and modern methods of making papers, which occurred during the latter part of the nineteenth century. Shortly after this took place, those concerned with the preservation of valuable documents and publications began to find that many of them were turning yellow and crumbling to dust. This continued to be noted by librarians throughout the world, and even as far back as the eighties we find investigators and librarians expressing alarm over the situation. From that time on there has been continuous discussion of the subject, and much study of it, but, as will be shown later, nothing very conclusive has resulted.

At present, the subject is being actively considered in nearly all civilized countries, and the demand is becoming more and more insistent that some criteria of permanency be established. The League of Nations has actively taken up the subject as of world-wide importance and has established an international committee to deal with it. This subject was given considerable discussion at the First World Library and Bibliography Congress held in Rome last year. It is being actively considered by various library associations, both abroad and in this country. In this country active research is being conducted by the various government laboratories, by the Rag Content Paper Manufacturers, and by a number of separate paper manufacturers. Last year the Department of Commerce was requested by various representatives of the paper industry to extend its assistance in a systematic effort to formulate commercial standards of this kind, and such assistance is being given.

Development of Modern Papers

As previously indicated, practically no difficulty was experienced in the preservation of papers up to the introduction of the use of wood and the speeding of paper-making processes in the latter part of the nineteenth century.

There are well-preserved papers made from a variety of materials dating back a great many centuries. Some of these are Chinese papers made from the mulberry tree, Egyptian papyrus papers made from a swamp grass, and papers from many sources made from linen or cotton rags. The earlier papers were made slowly and carefully by hand, and without use of chemicals. The fibers were separated by hand, and their bleaching and drying were by the action of sunlight and air only. Later, materials such as animal glue and starch were employed to give the papers better writing and printing quality; the use of alkalis to assist in cleaning and defibering the raw material and chemicals for bleaching it was initiated; and the Fourdrinier paper machine, with other paper-making machinery, was developed to speed the paper-making processes.

In spite of these advances, due to the limited supply of raw materials in use and the high production costs, paper remained an expensive commodity. The chief raw material used at this stage was rags, even newspaper being printed on rag paper. As

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[1] Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

[2] Chief, Paper Section, Bureau of Standards.

Contributed by the Printing Industries Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

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education advanced, the demand for cheaper papers increased, and this resulted, starting early in the nineteenth century, in a determined effort to find cheaper fibrous raw materials and less expensive ways of making paper. The vigorous attempts being made now to utilize various waste-plant materials is reminiscent of that period. Straw was successfully made into good grades of paper, but the desired results were not secured until means of pulping wood were discovered, as here was an extremely abundant and inexpensive raw material which was well adapted for mass production in an inexpensive way. This rapidly supplanted very largely other materials for all except the very highest grades of printing and writing papers. The use of straw in paper was quite common around 1830. This was quite largely supplanted by wood pulp, produced by caustic soda treatment, in the sixties; ground wood, and chemical pulp produced by the acid-sulphite process, came into being between this time and the eighties. These last two developments gave the very inexpensive paper ideally suited for newspapers so far as manufacture and cost are concerned, but the ground-wood pulp, or mechanical pulp, as it is also called, considerably complicated the permanence situation, as will be explained later. With the development of processes for utilizing wood, came the development of the inexpensive rosin, aluminum-sulphate sizing, and increase in size of machinery and speed of its operation. Most wood-fiber papers are produced today by a practically continuous operation, on a huge scale, rapidly and with a minimum of labor.

A recent development in the pulping of wood is the production of fibers from wood simulating in purity, strength, and other paper-making qualities the cotton or linen fibers. These wood fibers are produced by combinations of the usual chemical pulping processes, and some variations in the usual after-treatments, with careful attention to each detail. Another fairly recent development is the sulphate pulping process, which is an alkaline treatment employing, in addition to caustic soda, sodium sulphide. This, in various modified forms, is in quite extensive use for the treatment of pine woods as it is particularly well adapted for woods having a high rosin content.

With increase in depletion of wood and consequent increase in its cost there is today, as previously noted, a recurrence of the extensive efforts made a hundred years ago to utilize grasses, straws, and other plant stalks. This class of materials is used to an appreciable extent in countries deficient in forests, but their use in this country is still in a process of development. Nevertheless, this class of raw material should be considered as it may possibly be a factor in the near future.

At the present time, then, the three main sources of paper-making fibers, so far as writing and printing papers are concerned, are rags, wood, and grasses and straws. A brief description of the processes used in isolating the paper-making fibers may help to a better understanding of the following more technical discussion.

Rags are classified into a number of different grades depending on their cleanliness and purity. Cotton rags are largely used, but linen rags are used to some extent. After sorting and examination to eliminate extraneous materials, they are cooked with lime or caustic soda, washed, defibered in a beating engine, and bleached, usually with chlorine or calcium hypochlorite. The highest grades of rags are termed "new rags," and are clippings, threads, etc. obtained directly from textile manufacturing operations. The lower grades are used rags, and being more or less dirty and sometimes colored, they require more severe chemical treatment than the new rags for isolation of clean, white fibers.

Likewise there are various grades of pulpwoods, but their grading is more particularly in respect to the nature and amount of fiber in the wood. As mentioned, both alkaline and acid pulping processes are used, and the chemical treatment is otherwise much the same as for rags, except that it is necessarily much more drastic because the cellulose of trees is associated with a far larger amount of organic impurities than that of rags. The ground-wood or mechanical pulp is produced, as the name implies, by simply defibering the wood by grinding, with no chemical treatment.

The other main source of paper-making fiber is esparto grass, which is used quite extensively abroad, particularly in England. It is pulped by the caustic-soda process, and the chemical treatment in general is similar to that for wood but is less drastic.

The paper-making processes are essentially the same for all classes of papers so far as the main details are concerned. The fibers are beaten; the sizing materials, usually rosin and alum, fillers, coloring matter or other materials used, are added to the beater; the paper is formed on a Fourdrinier wire and then dried on steam-heated cylinders. In the case of writing papers, the paper may be "surface sized" by passing it through a tub of animal glue or starch before drying it. Such papers are usually further dried and seasoned by hanging the sheets on poles and letting them "air-dry" or by various modifications of this operation.

Aging Properties of Papers

The evidence is clear, as before stated, that the period when deterioration of printing and writing papers first became noticeable is coincident with the introduction of modern paper-making processes and the use of wood fibers. The evidence is very contradictory, however, as to the cause of the deterioration. There is general agreement that the paper should be as free as possible from active chemicals such as iron, sulphur from cooking processes, chlorides from the bleaching processes, rosin and aluminum sulphate from the sizing processes; and that no matter how high the initial quality of the fibrous raw material may be, the fibers may be ruined so far as permanence is concerned by poor practice, in cooking, bleaching, or beating. In respect to influence of the fiber components of paper, however, the literature reflects the same difference of opinion as exists today. There is quite general agreement that crude fibers such as ground-wood fibers—that is, fibers having little or none of their large content of impurities removed—are very impermanent, but there is wide difference of opinion as to the aging qualities of fibers from different raw materials, refined by chemical pulping processes and by bleaching. Many express the view that cotton fibers are essential for permanence, basing their opinion on the excellent record of such papers in the past, on the fact that the high initial purity of this fiber minimizes the further purification required, or in some cases on experimental evidence that the wood fibers as usually prepared are less stable than the cotton fibers.

Unfortunately, experience with the actual aging of the modern types of printing and writing papers does not in any case extend back very far. The present types of rag-fiber papers probably were not duplicated more than 125 years ago at the most, as the use of rosin sizing and aluminum sulphate now employed in their manufacture originated about 1807. The modern types of wood-fiber papers are younger, the newsprint grade originating apparently about 40 years ago and the fine wood-fiber writing and book papers a few years later. Herzberg, however, reported in 1907 results of retests of papers stored by the German government paper laboratories. These showed that there was no marked difference between the all-rag fiber papers and the all-wood fiber papers. A. D. Little stated in 1903 that properly purified wood fibers such as bleached sulphite and soda fiber have shown no sign of change in twenty years.

The National Bureau of Standards is making a systematic study of papers of various ages secured from libraries and other sources. While this has been in progress only a short time, the

tests so far made indicate that fibers from low-grade materials as prepared by the modern processes may have quite a long life. A sample of soda-sulphite book paper 30 years old was found to be apparently as good as when first made. Sulphite bonds around 15 years old were likewise very well preserved. The most significant test results, however, were those made on specimens from old newspapers secured from the files of the New York Public Library. These papers were published during the period 1866–1880. Those published from 1866 to 1873 were in excellent condition and were composed entirely of chemical fibers from a wide variety of materials, rags, esparto grass, straw, and wood. Two of these papers composed entirely of esparto-grass fiber and one containing 80 per cent of straw fiber are of particular interest as further evidence that papers having considerable permanence were produced from low-grade materials. The papers issued from 1874 to 1880 all showed more or less deterioration and contained ground-wood fiber mixed with the various chemical fibers found in the previous papers. Similar results have been obtained in tests of old books. In many cases several different kinds of paper were used in the same book. When composed of chemically refined fibers, whether from rags, esparto, straw, or wood, in most cases the papers were well preserved, but pages containing ground-wood pulp are usually badly deteriorated. There are exceptions, however. That is, occasionally papers composed of refined fibers from all the sources mentioned have been found badly deteriorated. It appears that when ground-wood fibers were first introduced they were used indiscriminately in all classes of publications, even those of permanent value, and that this use continued until the evident instability of this class of fibers became apparent. No doubt this practice has been largely instrumental in forming the opinion held by so many librarians that all fibers from wood and similar materials are very impermanent, no matter what their character may be.

Tests of representative samples of the present commercial writing and printing papers were reported recently in a Bureau of Standards publication. These tests were made along the same lines as those reported by Kohler and Hall of the Swedish government. They included, in addition to the usual strength and purity tests, an accelerated aging test made by heating the papers and finding the degree of stability as indicated by the degree of retention of the strength and desirable chemical properties. While the applicability of the latter test is questioned by many, it, together with the other tests, indicated the same thing found by tests of old papers, that low-grade fibrous materials may be so processed as to have a high degree of permanence, and, on the other hand, that high-grade fibrous raw materials may be so processed as to produce impermanent papers. Highly purified rag and wood fibers were found to be similar in cellulosic purity, that is, content of alpha cellulose, and in paper-making characteristics. They reacted similarly in the paper-making processes, both forming in the beating treatment the fiber fibrillae necessary for high strength and endurance, without excessive shortening of the fiber and without excessive impairment of the cellulosic purity. Chemical and physical tests of papers made from such fibers showed the same similarity in results. But tests of fibers from the same sources and of papers made from them, having a lesser degree of purity and strength, showed gradings downward similar to each other. All of these findings are in line with the predominating evidence that, chemically, cellulose is the same no matter what the source, and that celluloses very similar in both chemical and physical properties can be isolated from widely different materials.

All of this review of the available information on the qualities that make for permanence of paper leads inevitably to the conclusion that the degree of stability of paper is dependent primarily on its purity. The degree of purity of the fiber and the purity of the paper in respect to active chemical components are the prime considerations.

Any one who wishes to review in detail the literature on permanence of paper will find the "Bibliography of Pulp and Paper Making," by C. J. West (Lockwood Trade Journal Company), and "Causes and Prevention of Deterioration in Book Materials," by Robert P. Walton (New York Public Library), prolific sources of information.

Estimation of Permanence of Paper

Following is an outline of complete procedure suggested for estimation of the permanence of papers. This takes into account the more important factors affecting the permanence of paper indicated in the preceding discussion.

The first consideration is whether the paper has sufficient strength to withstand the mechanical stresses incident to its use. Bond and ledger papers, for example, must have a very high degree of strength as they are often folded repeatedly and are subjected to considerable handling in general. Such papers are usually surface-sized with glue or starch, and considerable increase in the strength of the paper is secured in this manner. As in some cases this increased strength may not be permanent owing to the use of faulty materials or to faults in the sizing process, whenever possible a sample of the paper not having the surface sizing is secured, and this, as well as the sized paper, is tested for strength. The strength of book papers, on the other hand, is of lesser importance, because they are well protected by the binding. Particular attention is given of course to the color, texture, and cleanliness of papers intended for long use.

The next consideration is to judge how well the paper will retain its strength and color, as both of these properties are subject to deterioration induced by chemical reactions within the paper.

The permanence of the color, so far as light effect is concerned, is tested by subjecting the paper to an artificial light which simulates sunlight but which has greater intensity of active rays. Care is taken in this test to avoid excessive heating of the paper. The paper is exposed to light from a carbon-arc lamp for a period of 24 hr., at a temperature of 40 deg. cent. A numerical measure of the fading is obtained by means of a colorimeter.

The testing for resistance to chemical deterioration is more involved. The basic constituent of paper fibers is cellulose. Pure cellulose is the most permanent organic material occurring in nature. By itself, it will remain unchanged under normal conditions indefinitely. It is very susceptible, however, to deterioration induced by certain associated impurities. Degraded celluloses, such as oxycellulose and hydrocellulose, apparently have a very harmful effect. The presence of modified celluloses of this kind may be due (1) to insufficient purification of the fiber and (2) to changes in the pure cellulose caused by adverse influences in the paper-making operation. The content of pure cellulose, commonly termed "alpha cellulose," is determined by dissolving the other fiber constituents with caustic soda. The "copper number" is used as a measure of the degraded celluloses. It represents the amount of copper reduced from a copper solution by a given amount of the paper. Resinous materials, either introduced as rosin sizing or associated with the fibrous raw material, are known to have a deleterious effect. The paper should contain a minimum of any material that is active chemically. Acids are particularly harmful. The amount and the nature of the ash content are important. If no mineral filler has been used, a low ash content is an indication of careful cleansing of the paper materials. A chemically inert filler, such as the china clay commonly added to book papers, is regarded as harmless and, in fact, as having some fiber-protective value in respect to chemical influences.

Complete information cannot be obtained by analysis alone,

as at present little is known of the deteriorating effect of any given combination of paper constituents. For this reason an accelerated aging test is considered a valuable supplementary test. This is made by heating the paper and finding the degree of deterioration of its physical and chemical properties. This treatment is presumed to simulate the chemical effects of many years of natural aging. The paper is heated for 72 hr. at 100 deg. cent., and then the pertinent chemical and physical tests are repeated. While this is merely an empirical test and its time relation to actual aging is not known, its principle appears to be sound theoretically, and the gradings obtained with it are consistent with the permanence history of papers. A high degree of resistance to the heat effect, particularly respecting retention of folding strength and alpha cellulose, as well as a minimum increase in copper number, are regarded as favorable indications of permanence.

The procedure outlined is used by the National Bureau of Standards and is practically the same as that used by the Bureau of Standards of Sweden. It is also being used by several commercial testing laboratories.

The strength of the bond and ledger papers is usually determined by the folding test. This test is not satisfactory for most book papers owing to their lesser degree of strength, but no doubt should be used for the higher grades. The tensile test appears to be the most satisfactory measurement of strength for book papers in general as it is readily applicable to all grades and appears to be more in line with the stresses to which such papers are subjected in their use.

Determination of copper number of paper and of its alpha-cellulose content has not been studied very much until recently. Considerable work on such methods by the Bureau of Standards has resulted in development of procedures by which results of copper number determinations can be reproduced within 0.1, and results of alpha-cellulose determinations within 0.3 of a per cent. This is quite satisfactory for the purpose. Quite satisfactory procedures for acidity are also available. The other tests required are covered adequately by the official paper-testing methods of the Technical Association of the Pulp and Paper Industry, except of course the accelerated aging test. As mentioned, this is an empirical test, and its applicability for the purpose cannot as yet be definitely proved. It is, without a doubt, a very severe test. From experience obtained with it, it would appear that any paper which satisfactorily withstands it without appreciable loss of its desirable physical and chemical properties must be very resistant to deterioration. On the other hand, a paper that shows considerable deterioration under this test is not necessarily suitable for temporary use only, but may give many years of service. This test or any one of the others suggested cannot be relied upon alone. They must be considered as a whole as apparently they all give valuable information. With further knowledge, a single test or a simpler combination of tests may be found which will give the desired result without such extensive and rather complicated procedure as that outlined.

Suggested Bases for Standardization

Probably the most complete technical specifications for the domestic printing and writing papers are the purchase specifications of the United States Government. More than twenty years ago, the Joint Committee of Congress on Printing appointed a committee to fix standards for printing and writing papers to be used as purchase specifications for the Government Printing Office papers. This committee has been continued and makes such annual revision of the specifications as are found to be advisable by experience with the papers, increased technical knowledge, changes in paper manufacture, or changes in the requirements of the Government departments. These specifications have recently been approved by the Federal Specifications Board for use by the other Government departments. The range of papers specified appears to be adequate for most commercial purposes, and as the specifications represent many years of experience and research they warrant careful consideration in formulating commercial standards.

The Government standards, as was necessary due to lack of experience with fibers from the lower grade materials, were initially based primarily on specification of source of fiber. The trend more recently has been in the direction of adding requirements for purity of the papers. At the present time the specifications for papers desired for the highest degree of permanence contain limits for acidity and sizing materials and have other requirements designed to obtain papers having as high degree of purity as possible. In all the fine paper grades, however, fiber composition and other composition requirements are still retained, although consideration is being given to modification in this respect.

In view of the present knowledge of papers and improvements of technic in manufacture of papers from the lower-grade materials, it is now possible in judging the quality of papers to rely on performance tests, and on such composition tests only as are indicative of the degree of purity. This is of course desirable in all specifications. When a purchaser tells a manufacturer how he must make material purchased, he, rather than the manufacturer, assumes the greater responsibility for the serviceability of the material. With elimination of composition requirements, the manufacturer is fully responsible for the performance of the material, but is unhampered as to the means he shall employ to ensure the required performance.

The technical details of importance in respect to permanence of papers have previously been touched upon more or less. The degree of strength is of prime importance. More than any other one test it reflects the grade of raw materials used and the technic used in the manufacturing processes. In addition to strength, acidity and content of rosin appear to be sufficiently important to warrant specification in all grades of paper except the lowest grade suitable for temporary use only. Inert mineral fillers or coating materials required for certain printing effects are almost universally considered to be protective rather than harmful as regards chemical deterioration of papers; therefore, the amount present is immaterial providing the desired strength is maintained, for of course addition of mineral matter weakens paper. Limits as to mineral contents were dropped from the German standard paper specifications in 1904. While probably the content of animal glue or of starch used for sizing paper should be as low as possible, there is little evidence that either of these has a harmful effect on paper. There is some evidence, in fact, that they, like most minerals, have a protective effect. As mentioned by Kohler and Hall, the Swedish Government investigators, there appears to be considerable difference in the effect of acidity due to internal sizing (that is, added to the paper-beater stock) and that imparted in surface-sizing the paper. The latter appears to be much the less harmful, and this should be taken into account in formulating acidity requirements for surface-sized papers. Mention has previously been made of the value of ash determinations in the case of writing papers containing no added mineral matter, as an evidence of how thoroughly the paper stock has been cleansed by the washing treatments.

For all except the highest grade of papers, specification of strength, acidity, and rosin content would appear to be sufficient. For permanent papers, in addition to these requirements, it is believed that content of alpha cellulose and copper number should be specified, as well as the constancy of these properties and strength, when the paper is subjected to a heat test. While such tests are time-consuming and expensive, these circumstances

should be disregarded in view of the importance of taking every precaution to make certain that papers of this grade will be of the highest quality.

In consideration of both usage of papers and the grades of papers available, it is suggested that they might be classified in four main groups according to their degree of cellulosic and non-cellulosic purity, as related to their service requirements. According to such mode of classification, the present domestic printing and writing papers may be grouped as follows:

Grade I. Permanent papers, having a maximum degree of purity; free from unbleached fibers, and highly lignified fibers such as ground wood. Indicative chemical properties: Alpha cellulose, 90 per cent; copper number, 1.5; rosin, 1 per cent; acidity, 5 pH; changes on heating 72 hr. at 100 deg. cent.: decrease in content of alpha-cellulose should be not more than 1.5 per cent; decrease in folding endurance not more than 25 per cent; increase in copper number not more than 0.5.

Grade II. Papers quite highly purified that may be expected to have a minimum life of 100 years; free from unbleached fibers, and highly lignified fibers such as ground wood. Indicative chemical properties: Alpha cellulose, 80 per cent; copper number, 2.5; rosin, 1.5 per cent; acidity, 5 pH.

Grade III. Papers having a fair degree of purity that may be expected to have a minimum life of 50 years; free from unbleached fibers, and highly lignified fibers such as ground wood. Indicative chemical properties: Alpha cellulose, 70 per cent; copper number, 5; rosin, 2 per cent; acidity, 5 pH.

Grade IV. Papers having a low degree of purity containing considerable organic impurities, suitable for current use only. This grade includes papers containing unbleached fibers, and highly lignified fibers such as ground wood.

All figures given for chemical components in these grade descriptions are upper limits, except for alpha-cellulose contents which are lower limits. Alpha-cellulose content and copper number are based on total cellulose content.

As stated in these grade descriptions, the purity limits are given merely as indicative and are not suggested as specification requirements, for the fixing of specification details must necessarily be done by the consumers and manufacturers directly concerned. In each of these grades, the establishment of two or more strength requirements for each weight of paper is necessary. Also, as less strength is required in book papers than in writing papers, different strength ranges are necessary for these two classes of paper. The strength requirements, of course, must be fixed with consideration of the kind and extent of mechanical stresses to which the paper will be subjected in its use. The strength gradations of the Government papers should be of particular assistance in this respect, although as they refer to a testing condition of 50 per cent relative humidity, they should be modified for commercial use to accord with the standard commercial testing condition of 65 per cent relative humidity.

Conclusion

Although this system of grading papers in respect to their permanence may appear to have a rather revolutionary aspect, it nevertheless seems to accord with the present state of knowledge of causes of deterioration. The composition standard has not proved adequate, since it does not definitely insure that a chosen paper will be permanent nor that a rejected one will fail to have satisfactory life. The usual viewpoint in connection with the composition standard limits permanent papers to a single class, and leaves wide open and without control all the other types of paper, which represent the bulk of printed matter in libraries and record files, and which, without doubt, include papers which are reasonably permanent. The suggested system of grading includes all types classified according to their probable degree of permanence as understood in the light of present knowledge. While obviously tentative, this system would appear at the time to best meet the practical aspects of the whole problem of maintaining permanent records, whether written or printed.

Technical Specifications for Paper Users

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This paper is a discussion of the use of technical specifications in the purchase of paper for use in the printing industry. Data are given to show the wide variations in quality between papers sold under the same designation. The experience of the Government Printing Office during the past 20 years is cited as an example of the practicability and value of technical specifications in the purchase of 50,000,000 pounds of paper annually. Benefits to be derived by the printer by a standardization of grades of paper and their purchase under technical specifications are described, as well as the benefits which would result to the manufacturers. Since standardization of grades of paper would be of considerable assistance in the purchase of paper under technical specifications by small consumers, reports from committees of the American Pulp and Paper Association are quoted to show the present attitude of part of the paper industry toward standardization.

PAPER is one of the most important materials manufactured today, both as regards its uses and its monetary value. The Department of Commerce states that paper and paper products manufactured in 1927 were valued at more than $800,000,000. The printing and binding industry in which paper is the principal raw material takes fifth place among the major industries of this country on the basis of value added to the raw materials by manufacture.

Practically all industries have standardized the purchase of their raw materials on the basis of technical specifications. The paper manufacturer, for instance, buys his materials such as pulp, rags, chemicals, and dyes in this manner. Printing and binding is the only large industry in this country today which does not buy raw materials on technical specifications. With the exception of the Government Printing Office and a few other large consumers, the printers of this country still purchase paper, their most important raw material, by rule-of-thumb methods.

It is possible to form an impression of various samples of paper by look and feel, but it is impossible to determine relative cost values or relative quality, permanency, and durability of different papers by any method except technical tests. The purchase of paper under such broad terms as bond or ledger, even when qualified by such terms as sulphite, rag, or rag content, will permit the delivery of paper of quality inferior to that desired or required. For instance, there are many sulphite bonds on the market today which will not comply with the Government specifications for this grade of paper. There is probably an even greater difference in the qualities of rag papers containing the same percentage of rag than in the case of sulphite papers, due to the difference in the quality of the rags used in their manufacture.

The test results on commercial brands of paper given in Table 1 show the wide difference in quality between papers having the same fiber content and sold for the same purpose.

For over 20 years the Government Printing Office has been purchasing paper under technical specifications. A study of the specifications in use today shows a considerable difference from those used several years ago. The bursting-strength test was formerly considered most indicative of the strength of paper. In recent years the folding-endurance test has been recognized as being much more indicative of the physical quality. For a time fiber analysis, weight, and folding endurance were considered ample tests for quality in such papers as bonds and ledgers. Recently, however, there has come a realization of the fact that chemical as well as physical tests indicate wide differences in the same kinds of paper. These tests are of special importance in those intended for permanent record use.

The Government specifications for paper are drafted by the Paper Specifications Committee of the Joint Committee on Printing. This committee makes an annual report to the Joint Committee covering the specifications for the following year. The changes recommended include results of research by members of the committee and any other improvements or changes necessitated by new developments in paper manufacture and in the printing and binding industry.

As a result, the Government specifications for any grade of paper represent the latest development in that particular grade. The Federal Specifications Board recently adopted the Government Printing Office specifications to cover all paper purchased by the various Government agencies in the field service, in order to eliminate any confusion which might result from the use of two sets of specifications.

The Government specifications for paper are composed of two parts: First, technical requirements covering physical, chemical, and microscopical tests which show the quality and character of the fiber used and insure their proper treatment during the process of manufacture; and, second, standard samples which show the desired characteristics of color, finish, formation, cleanliness, and watermark. Each individual specification has been drawn to cover the desired quality of paper for the purpose intended.

The experience of the Government during the past 20 years has proved definitely that not only can paper be purchased successfully on technical specifications but that it is the only method by which both buyer and seller are assured fair treatment. It assures the buyer that he will receive paper of the specified quality, and it assures competing firms that their competitors must quote on and deliver the desired quality. An added advantage of this method of purchase is that it invites competitive bidding.

Testing deliveries for compliance with specifications is as important as specifying the characteristic desired. This, of course, applies to any material purchased on technical specifications. Tests on deliveries insure the furnishing of paper of the quality specified, since all paper not complying with the specifications is rejected.

Technical specifications for paper should cover every desired quality. If surface characteristics are of primary importance,

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Contributed by the Printing Industries Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

TABLE 1 TEST RESULTS ON COMMERCIAL BRANDS OF PAPER

Fiber content		Sizing		Ash, per cent	Weight (17 × 22, 1000), lb.	Bursting strength		Folding endurance	
Rag, per cent	Bleached coniferous chemical wood, per cent	Glue	Starch			Points	Ratio (1000 average sheet basis), b.s. ÷ wt.	Machine direction (average), double folds	Across machine direction (average), double folds
				Bonds					
100		Present	None	0.7	39.4	73.5	1.86	2311	2133
100		Present	None	0.7	39.2	37.0	0.95	171	95
	100	None	Present	0.5	39.6	36.0	0.91	268	287
	100	None	Present	0.8	39.8	26.0	0.65	7	7
				Ledgers					
100		Present	Trace	1.0	56.2	91.0	1.62	1615	1695
100		Present	Trace	0.4	55.0	59.0	1.08	613	414
	100	None	Present	1.3	56.8	50.0	0.88	212	575
	100	None	Present	1.0	55.8	40.0	0.72	20	55

the physical and microscopical requirements should be so modified as to permit the manufacturer to achieve the desired results. All Government specifications are based on maximum and minimum requirements, and indicate the minimum quality of paper that will be accepted in each of the different grades. Specifications are not intended to be formulas for manufacture of paper, but merely define the minimum quality acceptable. Manufacturers may, of course, supply better qualities if they so desire.

At the present time technical specifications for paper are little used by small consumers, as manufacturers have not standardized their products on the basis of technical tests. The fact that the average printing plant is thus handicapped has been recognized by the United Typothetae of America, which cooperated in a research program with the Government Printing Office to standardize bond and ledger papers. The standardization refers to quality only and not to sizes and weights, which are fairly well standardized. The results of this work were utilized in Government paper specifications in 1925 and subsequently.

With the exception of chemical tests for the presence of certain sizing materials, the original recommendations covered only physical and microscopical tests. These recommendations have been slightly modified, and chemical tests have been added to aid in insuring maximum serviceability. Five grades each of bond and ledger papers have been found ample to meet all requirements of the Government service.

Another advantage which would be gained by the standardization of bond and ledger papers by the manufacturers is a considerable reduction in the number of grades, which would in turn result in savings in mill costs.

Since the general use of technical specifications in the purchase of paper would be aided to a considerable extent by the standardization of grades by the paper industry, the following is of particular interest:

The committee on Simplification and Standardization of the American Pulp and Paper Association, in a report submitted to the association last February, stated that the committee "is in favor of any practical standardization in the future—but that after a thorough investigation throughout the trade, it is found that the standardization of grade of paper is impractical at this time, as evidenced by the reports of the subcommittees." An examination of the subcommittee reports referred to as covering a thorough investigation throughout the trade shows them to represent the views only of the manufacturers, no expression having been obtained from the consumers.

Among the reasons for the impracticability of standardization cited in these reports are the following:

1 Paper making is an art and therefore intangible.

In some cases it may be an art, but the resultant product is the principal raw material used by the printing industry, and as such, its qualities can and should be expressed in definite technical terms.

2 Physical tests are not entirely significant elements in quality.

This is a well-known fact, and as stated, is but a half-truth, since modern technical specifications for paper do not depend on physical tests alone.

3 The life of paper is affected by the conditions of its use and the process used in correcting it into the finished job.

The fact that certain factors, at present not controlled, affect the life of paper is all the more argument in favor of making paper to comply with technical specifications which will insure the maximum service under such conditions.

4 Specifications for strength and durability would be misleading in the purchase of paper where appearance and attractiveness are the primary desiderations.

This argument is fallacious. Every paper must have a certain strength and durability, and properly drawn specifications include these qualities, even in the grades of paper mentioned, as well as the particular appearance or characteristic desired.

Particular emphasis is laid in the reports on the fact that printing and binding processes have not been standardized to the extent that the paper committees apparently think they should be and that as a result the processes have a variable effect on the life of the paper used. It is our opinion that such matters are not solely for the consideration of the paper manufacturers.

The paper committees further recommend that users should state their requirements to the manufacturers and allow them to determine the quality of paper required. This method of purchase is out of the question for the average printer that buys paper from a jobber who may or may not be acquainted with the properties of the papers he handles. The standardization of quality based on technical specifications and its purchase thereunder is the only assurance the printer has of obtaining paper of the desired quality.

In contrast to the report of the Committee on Simplification and Standardization is the first semi-annual report to the American Pulp and Paper Association of the work of their fellowship at the Forest Products Laboratory, Madison, Wis. Following are a few points from the report:

"To evaluate a material is to determine its fundamental properties and to express the results in numbers, technically correct and precise. These tools for the satisfactory measurement of properties are a prerequisite for sound technical advance in the industry.

"The whole structure of the pulp and paper industry depends upon the capacity of the sheet as marketed to fulfil the requirements imposed by the particular conditions of use. These requirements can always be translated into corresponding physical or chemical properties.

"Each mill is faced with the necessity for determining precisely the physical and chemical properties of the finished sheet in order that it may know for a certainty that the sheet will satisfy the requirements of the trade.

"Therefore the field of research selected is that of new and improved methods . . . for the evaluation of paper. This field touches directly the business of every mill . . . and holds excellent possibilities for results of large practical value.

"It is self-evident that the physical properties of the sheets are as a rule much more important than the chemical properties, and the problem is therefore limited by considerations of maximum utility to physical properties only.

"In considering paper as a structure, we have a material which is to a considerable extent analogous to the usual materials of construction. It is no more nonhomogeneous or discontinuous than timber or ceramic materials."

Mr. S. L. Willson, president of the American Pulp and Paper Association, in his address at the recent annual meeting of the association, made this significant statement:

"We shall hear today regarding a new departure in research work in paper chemistry, which I wish to commend to you. Like other activities, this has been neglected in the past. The mysteries of the world are being gradually unfolded through scientific research. Considerable progress by individual mills has been made, but no concentrated effort in the industry has ever been instituted until the present time."

The experience of the Government Printing Office is ample evidence that paper not only can be standardized but that in so far as the Government is concerned it is now standardized.

It is interesting to note that some of the paper mills represented on the committee which claims that standardization is impossible are regular bidders on approximately 54,000,000 pounds of paper purchased annually by the Government Printing Office, although these bids must be made strictly on specifications.

The following observations should be of interest to all paper purchasers:

1 Paper can be purchased on technical specifications as proved by the experience of the Government Printing Office for the last 20 years.

2 The purchase of paper on technical specifications and the testing of deliveries is the only assurance the purchaser has that he is receiving paper of the desired quality.

3 The use of technical specifications guarantees fair treatment to both buyer and seller. It assures the buyer of competitive bidding on the same quality of paper and likewise assures the manufacturer that his competitors are bidding on the same quality.

Discussion

K. A. Taylor.[2] From the standpoint of the paper manufacturer, specifications, if reasonably drawn up, are of distinct advantage in that they tell him exactly what the customer requires of his paper. If the printer could state all of his requirements in the form of specifications based on physical measurements, it would help the paper manufacturer a great deal.

For specifications to be of real value, they should be based on a careful study of the use and requirements of each grade of paper. The properties of importance in meeting these use requirements should be determined, and methods for their evaluation, if not already available, should be set up.

All of the properties of paper which are important in printing can be measured and the results expressed numerically. However, the writer believes that in the past most of the emphasis has been placed on strength tests in the evaluation of printing papers and not enough on certain other important properties, One of the most important properties in paper for fine printing, especially in a paper with a fairly rough surface, is the ability to yield enough under light compression to take a perfect impression during printing. The coefficient of elasticity under compression gives a numerical expression of this property.

[2] Oxford Paper Company, Rumford, Maine.

William R. Maull.[3] The paper industry, not unlike other industries, has made strides since the World War. Competition has hastened this, with a necessity for more accurate control of results and quality. Prices were lower before the war, and it was less costly to make mistakes. The users of paper are more exacting, and rightfully so. Their costs in turn are dependent on the workability and uniformity of their raw material on higher speed presses; and it was during this period, say the past fifteen years, when the chemists, chemical engineers, and other technicians were introduced, not as a replacement of any existing personnel, but rather to find out the reason for things and set up their control stations and testing laboratories. Mighty good work has been done during this period, and it is predicted there will be more to come.

Let a word be said here on behalf of the old paper makers, the machine tenders, beatermen, and superintendents who made paper and excellent paper previous to this period. They were the skilled help who through experience, the feel of the pulp, gaged its slowness or freeness, and they knew when to dump the beaters, how to set up the Jordans, and other important factors to get the closing up of the sheet or other characteristics desired.

These men of the old school will always be with us if we are building the higher grade papers. They are the skilled mechanics, as in the automobile industry of which this city is the center. If one is building a fine car, there are assemblies to be made, scraping of bearings, and exact fits that require the highest skilled mechanic; and so it is in the paper industry—it has a similar problem. The skilled help may use and is using the technical help and the instruments provided. The quality paper maker today has the experience of the industry, together with the science that has been developed.

Now we are facing the future and must aim to further improvements. To accomplish this we must go into even a closer contact with the printer and user. There must be more work done in standardization; research requirements must be defined and a better understanding result so that progress can be always forward—for without that inspiring hope and determination a healthy growth will not exist.

R. F. Reed.[4] Few modern industries can afford to purchase their raw materials without carefully drawn technical specifications. The printing and lithographing industries are, in general, behind the times in this respect. Many of the difficulties arising in the lithographing and printing operations would disappear if paper could be purchased on the basis of qualifications for the desired purpose, and these qualifications can undoubtedly be expressed in terms of technical specifications in conjunction with samples.

The reason for the present lack of standardization is obvious. The great majority of printing firms are small, and there are relatively few technically trained men employed in them. The same is true of lithographing firms, although, on the average, individual lithographic houses are much larger than print shops. Both are highly specialized industries and are based on methods which are largely empirical. Paper technologists in general know little about the paper requirements of lithographers and printers, and the latter know little about the technology of paper. When paper troubles arise in lithography or printing, contact with the source of the paper is usually through salesmen who are not technically trained and who can be of little real assistance to

[3] Vice-President and General Manager, Dill & Collins, Philadelphia, Pa. Chairman of Paper and Pulp Committee, Printing Industries Division, A.S.M.E.

[4] Director, Department of Lithographic Research, University of Cincinnati, Cincinnati, Ohio.

either side. Consequently, there is little background upon which to base technical specifications.

For this reason, the Lithographic Technical Foundation and the Bureau of Standards have planned a program of research for the development of technical specifications and tests for lithographic papers. It is expected that work on this project will begin at the Bureau on July 1, 1930.

W. G. MacNaughton.[5] On the desirability of specifications to cover every desired quality, the writer is in entire accord. It is when they enter into the question of the nature and source of the fiber constituents that reasonable objection can be raised.

The author states that there may be a greater difference in the qualities of rag papers with the same percentage of rags than between rag and wood fiber papers, due, in his opinion, to the difference in the quality of the rags used. He might also have said that there is a difference in papers made of identical fiber constituents of any furnish. The test specifications should determine the quality regardless of the composition.

The author would appear to want the specifications to determine the relative cost of production as well as the suitability for use, which, it must be admitted, is outside their province.

The only possible justification for requiring a paper to be made from specified fiber is that this is a relic of the "rule of thumb" period of purchasing as well as the making of paper.

[5] Manufacturing Department, International Paper Company, New York, N. Y.

Author's Closure

It would be desirable to have the specifications include tests which would show definitely the probable life of papers intended for permanent records. Such tests have as yet not been developed to the extent that they are usable.

The accelerated tests described by Mr. Scribner may possibly be of value in this respect. However, they should not be assumed to give the desired results until they have been checked against actual aging tests.

Our attitude with reference to permanent record papers is that the best rag papers have proved their permanency by actual aging, whereas the other paper-making fibers have not given such conclusive proof of their permanency. Therefore for all permanent record work we specify not only that rag fibers shall be used, but that the rags shall be new and that the finished paper must have certain physical characteristics as well.

The author does not agree with Mr. MacNaughton's statement that specifying the fiber content of papers, particularly those used for permanent record use, is a relic of the "rule of thumb" period of purchasing as well as the making of paper, since no definite proof is as yet available to show that fibers other than rag possess the required permanency.

It is true that there is a wide difference in physical qualities of paper made from different grades of rag as well as from different grades of wood pulp. The physical and chemical tests in the specifications are drawn to insure the desired physical qualities.

PI-52-7

The Printing Engineer and Printing Profits

By W. L. CHURCHILL,[1] NEW YORK, N. Y.

While the average earnings of printing and publishing plants is above the average of manufacturing industries, fully one-third of the businesses reporting showed a deficit averaging 9.26 per cent of their sales. Here is a highly technical industry manned by those who have had to devote years to specialized training and that operates with a high average of loss and with earnings insufficient to perpetuate the business. The engineer should be trained to think in terms of profits. Profits do not necessarily follow savings. Proper management requires that the engineering mind discover and eliminate the factors that prevent or destroy profits.



THE printing industry, in common with all of our manufacturing groups, is, as an industry, making a very unsatisfactory showing for its stockholders and owners.

According to the recently released Corporation Returns for 1928, 10,299 corporations under the general classification of printing and publishing earned a net profit equal to 8.36 per cent of their gross sales. The average earnings on the sales of all manufactured products for 1928 was 5.8 per cent. This places printing and publishing in a class better than the average of all manufacturing industries. Despite this comparatively high showing, 3511 firms, or 34 per cent of the 10,299 printing and publishing firms reporting, reported deficits averaging 9.26 per cent of their sales.

There were 6788 printing and publishing firms that reported profits averaging 11.17 per cent of their gross sales. These firms, representing 66 per cent of the total number reporting, were assessed income taxes upon net profits of $223,607,076. The remaining 34 per cent reported deficits of $29,815,071. The average earnings of the profit-reporting firms is approximately $32,000 per year. The average losses of those reporting no net earnings amounted to $8500 each.

From the standpoint of the dollar volume of business done by the firms reporting no profits, 13.8 per cent of all printing and publishing business is done at a loss averaging 9.26 per cent.

Even when the best possible interpretation is placed on these figures, the fact remains that one out of every three printing firms conducted its business at a loss during 1928, a very good business year.

It is possible that the losing group contains a much larger proportion of small firms not fully established. Offsetting this, however, is the fact that a very few large publishers are chiefly responsible for the good showing of the earning group. One of these large firms alone earned approximately 10 per cent of the reported net income of the entire industry.

Despite the apparent better position the printing and publishing industry holds over many other industrial groups, its profit showing as a whole is not one to be proud of, especially when the character of its work and its personnel are considered. Here there is a highly technical industry manned by people who have had to devote years to specialized training in order to conduct their work with skill and efficiency. Obviously there is something wrong when one-third of the firms in such an industry employing this exceptional skill and ability report deficits from their operations.

Here is a group of over 3500 firms that conducted their business at an average loss of 9 per cent of their gross receipts in 1928. Their customers obtained printing from them below the cost of its production and sale. These 3500 firms depleted their assets, and robbed their stockholders and owners to the extent of $8500 per firm, or an aggregate of nearly $30,000,000.

In addition to this distressing and indefensible situation, a large portion of the firms reporting profits have earnings that are insufficient to insure the perpetuation of their businesses. They lack sufficient surplus to invest in modern equipment that will enable them to keep pace with the developments in their industry and with the growth in demand for printing products. If these firms and the losing firms should be placed on an adequate profit-earning basis, manufacturers of printing equipment would no longer be hungry for business to fill their plants.

If it were possible to list the firms in the printing and publishing industry doing their full duty to society by earning adequate profits, the number would be very small. It has been estimated that less than one firm in twenty-five continues to operate upon a sufficiently profitable basis to enable it to remain in business for a period of 30 years without reorganization, refinancing, or some major change involving loss to stockholders and owners.

We are so accustomed to this situation that we give it little thought or concern. We accept it as a matter of course. We look upon it as an inevitable consequence of competition. We even in this enlightened day talk of the "survival of the fittest" and of "price wars."

There is no inherent reason for this condition in the printing or other basic industry. Engineering must see its outstanding opportunity and step in and correct this condition. This statement would seem to imply that the engineer is responsible for the present general lack of adequate profits in industry. He is responsible to the extent of failing to realize that he should long ago have assumed this responsibility.

To date the engineer has not been trained to think in terms of profit. His training has been directed toward lowering costs,

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[1] Economist-Engineer. Mem. A.S.M.E. Mr. Churchill has been connected in executive capacities with the American Pneumatic Service Corporation, Boston; The National Pneumatic Service Co., Chicago; Schreiber & Conchar Mfg. Co., Dubuque, Iowa; Yale & Towne Mfg. Co., Stamford, Conn.; McKinnon Dach Co., St. Catherine, Ont., and has served as industrial engineer and consultant with Stephen T. Williams & Staff, C. E. Knoeppel & Co., and the McDonald-Churchill Corporation. As industrial engineer and consultant Mr. Churchill has served a large number and variety of industries including gold-dredging in the Yukon, land reclamation in California, and during the war specialized on the development of shipbuilding, especially on the Pacific Coast. Since 1920 Mr. Churchill has devoted the major portion of his time to research into the economics of profits. In this work he has had the cooperation of a number of manufacturers associations as well as many private manufacturing firms. His discoveries in this branch of economics have resulted in his being called upon to address many associations interested in the improvement of industries and his written contributions have been widely read.

Presented at a meeting of the Metropolitan Section, New York, N. Y., April 4, 1930, sponsored by the Printing Industries Division, The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

increasing output, improving quality, and effecting savings. He has generally assumed that the accountant and salesman could be depended upon to see that his efforts resulted in profits.

Profits do not necessarily follow savings. The most perfect plant designed for the most efficient operation and operated with the greatest skill and economy can still fail to earn profits. It is not sufficient to condemn management as the cause for unprofitable operation. Management needs enlightenment on the specific and fundamental factors that destroy or prevent profits. It requires the engineering mind to discover and eliminate these fundamental factors.

The engineer's training and aptitude peculiarly fit him to determine and correct fundamentals that are responsible for the low average returns to stockholders and owners in the operation of industrial enterprises.

The engineer will need to study these causes and add to the range of his activities the ability to detect them and prescribe for their correction.

When the engineer fortifies his knowledge of engineering elements with a knowledge of how to convert these elements into earning power, he not only multiplies his own value and earning power, but increases the earning capacity of the institution with which he is connected. He increases the earning power of the employees, and he benefits business and society at large.

All of our material progress depends upon profits. Firms with ample profits reinvest a large portion of them in new buildings, equipment, research, and special services, making business for their suppliers and insuring their own growth, development, and perpetuation.

The author will briefly touch upon a few of the profit factors that at present are practically unknown and will endeavor to indicate why the engineer is specially qualified to understand and apply them. Take the question of the amount of profit that should be earned. If you are seeking a startling revelation of the ignorance existing in regards to what constitutes proper profit, the author will suggest that you ask various heads of enterprises with which you are connected this simple question: "How much profit should your business earn per year?" Not one business executive in ten will quote a figure sufficient to meet the requirements of business perpetuation.

This statement is based upon experience covering several hundreds of such business questionnaires. The inadequacy of the profit conceptions of these business heads explains the cause for many of the failures to attain profit levels that are safe.

A second question to ask is: "On what should the profit of each product be based?" Replies received from 125 manufacturers answering this question in combination with the first elicited 42 different bases and rates for profit determination. Not one of these 125 firms, whose businesses averaged over $1,000,000 each, had a correct basis for profit determination although 11 of these firms had a sufficient amount as an objective.

There is one definite basis for correctly determining the amount of profit that should be earned by any enterprise engaged in a profit-making industry. The formula is as complex and yet as definite as determining the horsepower of an engine. It is not dependent alone upon investment, sales volume, number of employees, or any other single factor. It requires a knowledge of values of equipment and facilities, of operations involved, of personnel requirements, and an understanding of the economics of production and distribution.

Obviously we should not ask the accountant or sales executive to add these typical engineering functions to the list of their attainments in order that they may arrive at profit objectives and be able to determine the profit to include in the prices or charges for all transactions. The engineer must include this among his duties. He needs only to acquire a little further understanding of economics in addition to the functions already included as part of his activities.

There are only some 8 or 10 fundamental questions of the nature of the two already mentioned that have to be understood in order that any worthy enterprise may function profitably. When they are all understood, "price wars" and "survival of the fittest" become obsolete phrases. There is no destructive price competition, and all worthy firms may survive because all become fit.

The engineer has concentrated chiefly upon means for cost reductions and improvement in quality and volume of output. He has been very successful along these lines, but all too often the improvements are directly or indirectly the cause of profit shrinkage through failure to secure such improvements for the betterment of profits.

One engineer recently examined a medium-sized plant to find means to improve the subnormal earnings of the firm. He found a way to reduce the cost of all of the products 5 per cent. He reported his findings to the president in the presence of the plant's sales manager. The latter spoke up and said: "Fine! Now we can reduce our prices 5 per cent and sell a whole lot more goods." The engineer said: "Hold on. I thought you asked me to find ways to restore your profits to their proper level. This cost reduction will enable you to do it if you sell no more than at present and get only the present prices. If you intend to throw these profits away in an effort to take business from other people, you shall not have the benefit of the plan."

To many it may sound like asking the engineer to usurp a function that belongs to others when it is said that the pricing of products and services must be based upon engineering and economic elements readily understood by the engineer. This statement is made, however, after several years' intensive study of the causes of sub-normal profits, covering first-hand knowledge in over a hundred manufacturing plants, including many printing establishments and printing departments.

Revising prices to accord with the known engineering and economic elements has in many instances converted losses to substantial profits almost overnight. This has been particularly true with plants whose engineering activities had developed a high level of efficiency, yet where profits had continued at subnormal levels or actual deficits were the order of the day.

There are as many cases of unintentional overpricing as there are of underpricing. Overpricing drives away business and abnormal profits with it. Underpricing encourages business, but with resultant losses that go with underpriced efforts.

Determining the correct basis for pricing is an engineering task, but when properly applied, insures continuous profits to any reasonably well-managed plant or industry. Under such conditions, super-management brings super-profits, indifferent management brings indifferent profits, but the proportion of enterprises so poorly managed as to make no profits will be very small. The engineer needs to become not only profit-conscious, but needs to assume the profit responsibility. Profits will more than ever call upon the additional abilities of the engineer. He need not forsake the special activities upon which he is engaged in order to insist upon such efforts as occupy his attention resulting in the full profit that should be obtained for these efforts.

No other profession or group is at present assuming the responsibility for profits, at least with any degree of success, as is evidenced by the limited profits of the industry as a whole. The fundamental factors that govern profits are quickly learned and easily understood. Application becomes a matter of simple routine.

The printing industry may be likened to a malarial district where a large portion of the individuals exist in a semi-sick state while a comparative few seem to continue in robust health.

We used to think that there was no help for this condition. It was in the air, and we took quinine and all kinds of patent medicines to minimize the effects and with the hope of prevention or cure. When the cause of malaria was discovered and malaria carriers were removed by drainage and similar measures, these districts were converted into healthful communities, in which any one may now live without fear of this ailment, by simply keeping the community free from the conditions which allowed the mosquito to thrive.

Likewise with industry, remove the fundamental cause of the low state of profit health (ignorance of profit economics), and all may enjoy the full vigor of successful endeavor. Industry needs to have the cause removed rather than administration of periodic doses of quinine.

The printing engineer, which includes not only the graduate engineer, but all whose activities are responsible for the efficient operation of a printing plant or plant manufacturing printing equipment, has an excellent opportunity to lead the way in the development of profit responsibility in the engineering ranks. He is dealing with people of above the average understanding, and cooperation is more readily assured than in industries manned by a less skilful class and where there is less interest in their own work.

Any printing establishment can place itself upon a profitable basis if it will indulge in sufficient study and application of sound engineering principles in the conduct of its operations. The engineer can bring about this desirable and necessary condition to the betterment of his own position and remuneration as well as to the benefit of all business and of society as a whole.

Profits mean progress. The greater the profits, the greater and more rapid our progress. There is a difference, however, between profits and plunder. Profits are profits only when all parties to the transaction benefit thereby.

The profitable industries pay the most profitable wages; that is, wages that provide a surplus to the worker over and above his necessities. This condition in turn encourages the best workers to flock to that industry and in turn develops their employing interests to higher profits and their products to greater demand because of their greater value.

These facts are splendidly illustrated in a comparison of the average earnings of workers in the various industrial groups as reported by the United States Department of Commerce for 1927.

The average yearly wages in manufacturing industries, including printing and publishing, were approximately $1300 in 1927. The average of all wage earners in the printing and publishing industry was $1782. Including salaried people (this industry pays nearly 40 per cent of its people by salary), the average earnings of all workers in the printing industry were $1847.

The textile industry, comparable in many ways to printing and publishing, paid an average of $1040 to each worker in 1927. The average profit earned by each worker in the textile industry for stockholders and owners amounted to $115. In the printing and publishing industry the average was $354, or more than three times the per capita profit of textile workers.

You are fortunate in being in an industry that has already displayed leadership in our industrial advancement and in demonstrating that high profits induce high wages and that the combination of both spells low costs that the consumer profits generously by as well.

We read about the wonderful value per dollar in our automobiles produced by another comparatively high-profit and high-wage industry; yet where will we get comparable value for the pennies and nickels spent in the printing industry?

Even with printing's enviable position in relation to other industries, we must not overlook the fact that one out of every three of the printing and publishing firms is losing money. We have a long way to go to put the entire industry upon a profitable basis and still further to bring the industry up to its full measure of profit so that it can continue to progress and add to the sum of our human development.

Discussion

MARTIN E. POPKIN.[2] This illuminating paper has opened a subject of paramount importance to business in general. The economics of profit has been so sadly neglected that we can be greatful to the author for his efforts in bringing the issue to the attention of the engineer as he has.

We engineers, in a broad sense, supply the world with its conversion tools, in one form or another. We create them, and consequently are responsible for their operation and for their effect upon those whom they intend to serve. As their parents we understand them best and organize their work so they will behave as all good tools should. In short, we are accountable for their being, but not accountable for what they make of themselves.

The great need for cooperative engineering administration in industry is equal only to the engineers' need to recognize the fact as such. The social economy of our age is conscious of the industrial influence upon our whole society and its culture.

Industry today is the very backbone of our civilization, and no other plays a greater part in our general economy than the engineer. Every political credo is vitally concerned with the relation between industrial structure and its part in the current need and welfare of society.

In the last decade the thought has preoccupied the minds of our most gifted scholars is concerning man and his machines.

It is an engineering age in which we are living. Engineers should recognize their obligation to industry only in so far as it serves society. Seeing that capital is intelligently used in the service of industry is part fulfilment of the engineer's responsibility.

Our whole art may be reduced to the premise that its intent is to supplement labor in the interest of a growing and more enlightened civilization. Any influence that may jeopardize this alliance is distinctly out of harmony with the engineer's concept of his work.

According to recently released corporate returns for 1928, a large percentage of the workers and technicians employed by one-third of the firms in the printing industry were insecure in their employment. While this is not peculiar to the printing industry, it is not a condition to which engineers need subscribe. The engineer as a supplement to labor must keep vigil to the end that it meet with no hazard which may be in his power to avoid. Profitable operation is the answer.

Our work is defined as "the art of organizing and directing men and controlling the forces and materials of nature for the benefit of the human race." With this as his creed, the engineer who does not concern himself with earning power breaks faith with labor, his greatest trust.

It is my privilige to be informed on the author's keen insight into the proper utilization of capital. His facts and his views, when known, are so startling in their simple truths that it is difficult to conceive how some one has not shouted them from the housetops heretofore.

Though the printing and publishing industry ranks better in profit earnings than the combined average of all manufacturing industries, it nevertheless showed one-seventh of its total dollar volume to be done at a loss.

[2] New York, N. Y. Assoc-Mem. A.S.M.E.

It is only reasonable to look to the engineer in matters of this sort. Profitable operation of industry is as much his concern as any other phase of his work. The printing engineers can render their industry invaluable service by bringing the need for scientific profit control to the attention of their principals and associates.

PI-52-8

Some Problems in Printing Standardization

By FRED S. ENGLISH,[1] NEW LONDON, CONN.

The lack of standardization of certain factors which enter into the design and use of cylinder printing presses is discussed in a general manner, particularly relative to the standardization of plates and bases, diameters of cylinders, depth of impression surface below cylinder bearers, height of bed bearers, sheets, forms, and names of parts.



IN considering the general subject for this session, i.e., "The Design of Flat-Bed Cylinder Presses," it appears that there are certain fundamental principles which are dependent upon various established or non-established standards. Undoubtedly these standards will be assumed or taken for granted in the development of the papers for the session. It seems, therefore, that a paper along these lines will be appropriate, considering particularly the lack of uniformity of many of these so-called standards.

Apparently little work has ever been done along the lines of standardization in the printing industry. To be sure, there is a standard height for flat forms, and the industry is approaching a standard thickness for flat plates and bases; there also is something in the way of standard sizes of sheets, and partially standardized catalog, book, and magazine pages.

The U. S. Bureau of Standards, cooperating with various organizations, has recommended standard sizes for paper, catalogs, commercial forms, checks, etc., but apparently they are not closely followed.

Practically everything else has been left to the varying ideas of the different equipment and material manufacturers or to the users of such equipment and material.

This paper will deal with some of the difficulties which, due to this lack of basic standards, face the manufacturer and user of printing machinery, with the hope it will have a part in the development of much more complete standardization than we have at the present time.

Type Height. The height of flat forms is already standardized in this country at 0.918 in., and this, of course, applies to both type and plates.

Height of Bed Bearers. The height of flat-bed bearers, however, is not standardized, some manufacturers apparently considering that they should be exactly type high and others that they should be just a trifle lower.

It is possible that some makes of presses run better with bearers of one height, and others with bearers of another height. Still, it would seem that the pressman would be better off if he always knew the exact relation of the top surface of his type-high form to the top surface of his bearers.

Standardization of bearer height, coupled with standardization of the depth of the impression, which will be considered later, would certainly tend toward more uniform make-ready and more uniform impression.

Height of Bases and Plates. An inspection of the catalogs issued by the various manufacturers of patent bases discloses the fact that some of these bases are made 0.757 in. high, while others are 0.759 in. high; and, what is possibly more serious, it is not uncommon to make bases to special heights to suit the whims of some particular customer. These special heights vary all the way from 0.688 in. up to 0.759 in. In addition there is still another height for original halftones. This, it seems, is absolutely necessary.

However, the International Association of Electrotypers is now working toward the standardization of the height of bases and plates. In order to invite discussion, its Standardization Committee has rendered a tentative report recommending the height of bases as 0.759 in., and the corresponding height of plates as 0.154 in. This leaves 0.005 in. for interlay or underlay.

This association feels that scientifically there should be no allowance for interlay, but recognizes that many pressmen demand it, and therefore allows for it. The fact is recognized also that light work may not require quite as heavy an impression, and therefore a plate thickness of 0.151 in. is recommended for such work.

Much confusion will be saved in the pressroom when this or some other standard is finally adopted and comes into general use, as it certainly will be more convenient for the pressman to know that he will find the same underlay conditions no matter what style of base he is using.

Curved Plates. When one comes to consider curved plates he finds one of the most unsatisfactory conditions with which the industry has to deal, both as to plate thickness and as to cylinder diameter. The International Association of Electrotypers reported that they found 7 different thicknesses of plates and 20 different diameters of cylinders as standards in fairly constant use in *one foundry*. These plate thicknesses varied from 0.152 to 0.375 in., and the cylinder diameters from 5 to 48 in.

The U. S. Bureau of Standards reports that it found one printing establishment in Baltimore which had 26 different curvatures or thickness of plates.

At first glance it would seem that the small-diameter cylinder would require a thicker plate than the large cylinder, on account of the greater tendency to buckle on the small cylinder. However, the evidence submitted by the Electrotypers Association does not prove this to be true, and it is making a tentative recommendation of 0.166 in. as a uniform thickness for all plates.

In this connection consideration also should be given to the depth of the recess in the cylinder for these plates, i.e., how much if any should be allowed for underlay.

Diameters of Cylinders. Standardizing the diameters of the cylinders on rotary presses presents a much more difficult problem, because the diameter of the cylinder is dependent upon the maximum size of sheet which the press is intended to print. This is especially true in the case of web presses, where the diameter of the cylinder is absolutely dependent upon the size of the page or group of pages which it is intended to print. Therefore in this case the sizes of magazine pages must first be standardized.

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[1] Chief Engineer, The Babcock Printing Press Manufacturing Company. Mem. A.S.M.E. Mr. English was born in 1873. He was graduated from the University of Vermont, in 1896. He has been with the Babcock Company since January, 1899, first as mechanical draftsman and in later years as Chief Engineer.

Contributed by the Printing Industries Division and presented at the Annual Meeting, New York, N. Y., Dec. 1 to 5, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

In the case of sheet-fed rotary presses it is true also that the diameter of the cylinder is dependent upon the maximum size of sheet which the press is intended to print, and in general every press manufacturer is striving to get the largest sheet possible on the smallest diameter of cylinder, because the speed as well as the cost of his press is dependent upon the cylinder diameter.

Notwithstanding all this, it would seem that 20 different diameters are more than is necessary and that a series of cylinder diameters could be worked out which would adequately cover all requirements, provided the size of the pages of magazines and mail-order catalogs, as well as flat sheets, were properly standardized.

Even suppose it were found that 20 different cylinder diameters were necessary, is it not possible that standardization of these 20 sizes would prevent the future addition of more odd sizes?

With the thickness of plates and the diameters of cylinders properly standardized, the plate maker would have an opportunity to equip with standard plate-making machinery, which could be used for the requirements of many different customers, instead of being obliged to provide new equipment every time a new size or style of press is brought out, and having such special equipment stand idle except when it is being used for one special customer or group of customers. The cost of plates would undoubtedly be reduced, and at the same time the quality of the plates would be improved.

Depth of Impression. The depth of the impression surface on impression cylinders, i.e., the distance from the surface of the bearers to the body of the cylinder, is different in different makes of presses. This means a different total thickness of the tympan, and consequently a varying degree of solidity, so that the pressman who works on different presses must carry these varying conditions in his mind. Possibly this is of minor importance, but certainly standardization would be helpful, and it should not be a difficult thing to achieve.

Height of Cutting and Creasing Rules. There is no standard height of cutting rule for use on cutting and creasing presses. Two heights are in common use, 0.923 in. and 0.937 in., but in addition there are several other heights in fairly common use, running all the way from 0.916 in. to 1 in.

On account of this lack of standardization, cutting and creasing presses must be flexible, i.e., they must be built so that they can be adjusted readily to accommodate these different heights of rule, and the manufacturers must carry a miscellaneous assortment of bearers in stock.

It would not be difficult for the manufacturers of these presses to build them for a standard height of rule, but it is difficult to persuade the proprietor of a folding-box plant to use any height of rule but that to which he is accustomed.

Creasing rule is not so easily standardized, because the height must vary somewhat with the thickness of the stock being run. Besides, there is another element which enters into this situation, and that is the fact that different pressmen have different ideas as to the best height of creasing rule for any particular thickness and grade of stock.

Possibly these ideas could be standardized, and this, with standardization of the cutting rule, would reduce the number of sizes of creasing rule materially.

Standard Sheets and Forms. There are certain standard sizes of sheets in fairly common use, but it is not uncommon for a printer with a large contract to order stock especially suited to the job. Why? Simply because the job itself is non-standardized.

To be sure, there have been attempts to standardize catalogs, but the standard sizes do not seem to be followed very generally. This may be because the advertising experts do not fully understand the importance of such standards, but it is more likely due to the fact that a large proportion of printed matter is laid out by non-experts.

If the printer would adopt certain standard sizes of printed matter, both in sheet and form sizes, and then insist that all jobs be made to those sizes before considering them, it would assist very materially not only the paper mills and jobbers but the plate makers and the press manufacturers as well.

For instance, suppose the press manufacturer is designing a new press to take, say, as maximum, a 25 × 38 in. sheet. The first problem he encounters is, How large a form must be printed on that sheet? The present answer is 25 × 38, which all know is almost impossible. Notwithstanding the practical impossibility of doing it, sooner or later some printer is going to take such a job and try to run it on that press. He will get in endless trouble, and probably wind up by running it at a slow, expensive speed and with less than the full number of rolls covering the form.

Suppose it were thoroughly understood that it cannot be done and that no printer would consider the job until it was made to standard size; just imagine how much trouble would be saved for all concerned.

One might go a step further and insist that invoices, bills of lading, bank checks, and a thousand and one other things of that kind should all be in conformity with the U. S. Bureau of Standards recommendations.

Names of Parts. Except for a few of the larger and more prominent parts, the names which are used in describing the various parts of printing machinery and which must be used by the printer in ordering repairs vary according to the ideas of the manufacturer. To be sure, each different style of machine has some parts which are unlike those on any other machine, and for these the manufacturer must coin a name, but if the basic units had standard names it would greatly assist the printer in ordering his repairs.

For instance: A printer orders a fountain roll. He actually wants the composition roll which transfers the ink from the fountain, but he gets the roll which works inside the fountain proper and delivers the ink to the composition roll in question. Why? Because the manufacturer who received the order calls this roll, which works inside the fountain, a fountain roll; according to that manufacturer's code, the printer really wants a duct roll.

You can readily imagine how the printer goes "up in the air" and the harsh names he calls the manufacturer. Some people call this roll which works inside the fountain a "ball" or "bole" instead of a "roll."

Some manufacturers call the parts on which the bed runs "tracks;" others call them "way frames." We have "feed guides," "side guides," "drop guides," "drop fingers," "lazy fingers," "grasshoppers," etc., without limit and all mixed up. Why not unscramble the mess, make a fresh start, and then try to teach the printer to use the correct names?

Summary. No attempt has been made in this short paper to cover all the possibilities or to define just what the various standards should be or how the work should be done. It is intended, rather, to show the vital need for more standardization in the printing industry, with the hope that it will help lead the way toward standardization of many units which are now left entirely to the imagination of either the printer or the equipment manufacturer.

Discussion

OTTO W. FUHRMANN.[2] A standardization of the distance between bearer top surface and body of cylinders, viz., the

[2] Director, Division of Graphic Arts, New York University, New York, N. Y. Assoc. A.S.M.E.

thickness of packing, is highly desirable, in view of the variable factors in the compressibility of the packing material and the "make-ready" and also in the varying heights of such printing elements as wooden blocks, type, slugs, and plates on patent bases. The pressman's greatest trouble lies in getting a level surface of his form, particularly if it is of a mixed character. His "make-ready" could be reduced to next to nothing if his forms were precisely level. But that is a different story with which we are not concerned here.

Mr. Eney's[3] suggestion that every cylinder be marked plainly with the amount of packing it is to carry so as to have the printing line on that periphery of the cylinder that corresponds to the length of the form is excellent; if it were followed the pressman would never be in doubt whether to add to the underlay or to the packing, and this would prevent the all too frequent overpacking with its resultant troubles of wear on plates, stretching of sheets, and pulling out or tearing of top sheets.

The lack of standards among presses of different makers means that the education of pressmen to a more uniform procedure of make-ready is made difficult. The writer is speaking from the standpoint of the practical printer who finds the great majority of the shops equipped with a variety of models and makes. The various standards for packing, height of bases, and thickness of plates should not be fixed arbitrarily, but on the basis of a sensible procedure of make-ready that has as its aim perfect contact of all printing surfaces and not the idea of bettering the photoengraver's work.

Charles H. Cochrane.[4] There seems to have been little or no thought on the part of printing-press designers to provide for sheet heaters and electric neutralizers on their machines. Usually no space is left for these attachments, and this adds to the fire danger of gas heaters, which can be made wholly safe where there is room. If the machine designers would leave such space and also provide uniform means of attachment, as bolt holes or crossrods of uniform diameter, this would go far toward standardizing heaters and neutralizers. One manufacturer has cited seventeen sizes of their flat-bed presses. The writer's company has to make over 250 sizes and styles of heaters to fit all of the familiar types of printing machines.

One discussor has inquired as to the cause of static electric troubles and the desirable heat to employ in the pressroom. A recognized standard of heat and humidity for the printer would help everybody. The writer's experience suggests that most pressrooms are kept too hot, and in winter far too dry. He recommends 70 deg. fahr. as the ideal temperature, with 50 to 55 per cent relative humidity. May we hope that some time soon the A.S.M.E. Printing Industries Division will be able to give an entire session to the problems of static electric troubles and offset and the several cures. Humidification appears to be looming larger and larger as the fundamental remedy.

Dewey Thibault.[5] The pressman is entirely at the mercy of the allied trades as to what he is supplied to turn out a good job of printing, and everything that he performs in make-ready is done to make up the discrepancies of the material that is furnished him. It would be a great help and saving to his employer if some method of standardization on evenness and thickness of plates, bases, press bed, and cylinders of presses could be accomplished.

The writer is much impressed with the meeting and everything that the engineers are doing to produce precision machinery, but there seems to be a lack of investigation on the part of the engineers as to possibilities of overcoming the pressman's greatest difficulty, offset.

The speeding up of machinery has added greatly to this difficulty as the sheets are delivered to the jogger so fast that there is no time for the ink to set. This difficulty had to be contended with when machines were hand fed and were running slowly, so it can readily be seen what the fast machines have added to the hazard.

An investigation of this difficulty on the part of press engineers will certainly result in some method of overcoming it, and will greatly help the printer in getting maximum production from these fast presses. The paper and ink manufacturers are doing everything in their power to solve this problem, but the press manufacturers with their high-speed machinery are making it doubly hard for them to do so.

Ernest F. Trotter.[6] The most interesting paper by Mr. English seems to call for a crystallization of the valuable suggestions therein made, and therefore two resolutions, on the subject of machinery and equipment standardization and on printing sizes of paper, are offered, as follows:

Resolution on Standardization of Equipment

WHEREAS, no standards for various types of equipment used in the many branches of the graphic arts have ever been adopted, and

WHEREAS, the lack of concrete information as to the requirements of the industry has caused endless confusion and the creation of many equipment units for which there is little or no justification, as well as tremendous expense to manufacturers who have to service such equipment, and

WHEREAS, it is obvious that better printing will result when all branches of the industry can cooperate in observing certain recognized standards; therefore be it

RESOLVED that we request The American Society of Mechanical Engineers to appoint a committee to investigate and report upon the need for standardization in the printing industry.

Resolution of Thanks to Paper Mills

WHEREAS, the paper read by Fred S. English, chief engineer of the Babcock Printing Press Manufacturing Company, on "Problems in Standardization" points out that any effective program of standardization in the printing industry is dependent upon adoption of standards in magazine, book, catalogue, and form printing sizes, and

WHEREAS, several large paper manufacturing companies have undertaken extensive advertising campaigns direct to the consumer on the subject of standardization of paper sizes; therefore be it

RESOLVED that this meeting go on record as commending these campaigns and further that the paper mills be officially advised of our appreciation of their splendid efforts.

Both resolutions were unanimously adopted.

Author's Closure

Since the paper was written, the International Association of Electrotypers, at a meeting held in September, 1930, adopted the following sizes as standard:

Thickness of flat plates when made for patent bases (plus or minus 0.002 in. tolerance), in.	0.154
Height of patent bases	0.759
Thickness of curved electrotypes (plus or minus 0.002 in.) for cylinders of usual diameter	0.187
Thickness of curved electrotypes (plus or minus 0.002 in.) for very large cylinders	0.250

[3] Summerfield Eney, Jr., Presswork Expert, Champion Coated Paper Company, Hamilton, Ohio.

[4] President, Utility Heater Company, New York, N. Y.

[5] New England Representative, Babcock Printing Press Manufacturing Company, Boston, Mass.

[6] Managing Editor, *Printing*, New York, N. Y.

PI-52-9

Design of the New Harris Automatic Two-Color Flat-Bed Press

By ALFRED S. HARRIS,[1] CLEVELAND, OHIO

A recent design of two presses, one a single-color and the other a two-color press, includes the standardization of parts and units to such an extent that 72 per cent of these parts are common to both presses. A few of the points described in the design are those contributing to rigidity of frame, impressional strength, uniformity of bed travel during the printing stroke, evenness of ink distribution, and accuracy of register. Accessibility to its adjustments and convenience for make-ready also received attention.



THE Harris-Seybold-Potter Company recently announced to the trade the manufacture of a single-color and of a two-color 20 × 26 two-revolution automatic flat-bed press complete with pile feeder and pile delivery. A general description of these presses together with some details of the mechanical construction may be of interest.

Early in 1928, the design of these presses was started with the idea in mind to make available for the printer a single-color and a two-color press of small size capable of producing the finest quality of printing at high speed. A few of the points in press construction contributing to quality printing are rigidity of frame, impressional strength, uniformity of bed travel during the printing stroke, evenness of ink distribution, and accurate register.

The speed of production not only depends on the ability of a press to rotate at a high number of revolutions per minute, but also on the accessibility of its adjustments and the convenience for make-ready. Particular attention also was given to the standardization of parts and units. How well this has been accomplished is evidenced by the fact that 72 per cent of the parts are common to both presses.

The general specifications of the two-color presses are:

Maximum size of sheets press will handle, 22 × 30
Maximum form locked on the bed completely covered by four form rollers, 21 3/4 × 29 3/4
Center locked in chase, 21 3/4 × 28 1/2
Bed size, 27 5/16 × 31 1/4 width
Cylinder diameter, 17 in., ground to take a 0.065-in. tympan and equipped with tumbler grippers in first-color cylinder and breathing grippers on the transfer and second-color impression cylinders
Harris-type pile feeder accommodating a 46 in. height pile
Receding pile delivery accommodating a 38-in. pile.
Actual measurements on the base, 12 ft. 10 in. × 3 ft. 10 in.
Net weight of the complete press, 16,000 lb.

The side frames of this press (Fig. 1) are of extra-heavy construction and are designed so that the complete weight of the machine is supported by the frames. The feeder and delivery are of cantilever construction, attached to and supported on these frames.

The cross-members consist of two end girts and two center girts, one center girt directly under each impression cylinder, these in turn supporting the four tracks on which the bed travels. These tracks are cast in pairs and are rigidly fastened to the center girts, end girts, and press side frames.

The cylinders are held in positive contact with the bed bearers by means of a solid-steel toggle (Fig. 2) mounted directly above the cylinder center and so designed that when on impression there is no strain, either push or pull, on the cam or connecting rod which operates it. This rigid-impression toggle lock, together with the framing construction, has proved a factor in the overcoming of such trouble as guttering, building up of impression, and working up of type forms.

The main drive shaft is centrally located and journaled in three large bearings. All units of this press, such as impression cylinder, transfer cylinder, bed drive, and reverse, are driven direct from this shaft. The cylinders are rotated by a pinion on this drive shaft through an intermediate gear direct to the cylinder gear (Fig. 3).

This intermediate gear is swung on an arm pivoted around the drive shaft as a center and connected to the cylinder box by a link which insures the gears running on correct pitch line at all times, on or off impression.

The transfer cylinder is driven by a pinion on the same drive shaft through intermediate gears to the transfer cylinder gear. The registration at the transferring point from first color impression cylinder to transfer cylinder and from transfer cylinder to second color impression cylinder is controlled by register racks.

These register racks are not a part of the press drive, but are located on the end of the cylinder body.

The bed is driven by means of a pinion on the drive shaft meshing with the horizontal shifting bed gear. The reverse mechanism is also driven from the main drive shaft by a pinion through an intermediate gear.

The bed motion of this press is a 3 to 1 movement; that is, one revolution is used for the print stroke, one for the return or idle stroke, and one-half at each end for reversing. Two of the major reasons for using 3 to 1 movement in preference to a 2 to 1 movement were the conservation of floor space and the simplicity of the operating mechanism required.

The saving of floor space is due to the fact that a longer bed stroke is required with a 2 to 1 bed movement, when printing the same form and using the same size and number of form rollers. Where a 17-in. diameter cylinder is used in this press with the 3 to 1 movement, a 2 to 1 movement would require a cylinder approximately 1 1/2 in. larger in diameter.

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[1] Vice-President in Charge of Engineering, Printing Press Division, Harris-Seybold-Potter Company. Mr. Harris was born in Warren, Ohio, on June 10, 1891. After finishing grade school, he prepared for college in Morristown School, Morristown, N. J., and attended Princeton University and the University of Virginia. Since 1913 he has been with the Harris Automatic Press Company and its successor, the Harris-Seybold-Potter Company. During this period of time he has been connected with the following divisions of the company: Engineering, press installation, service and repair work, manufacturing, and sales engineering work.

Contributed by the Printing Industries Division and presented at the Annual Meeting, New York, N. Y., Dec. 1 to 5, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

The bed-driving mechanism consists of a horizontal shifting bed gear meshing with upper and lower bed racks fastened to the rack hanger, the bed being controlled on the uniform printing stroke by the upper rack and on the return stroke by the lower. While the bed motion is 3 to 1, the bed gear is 6 to 1, giving the added advantage of a shallow rack hanger with a corresponding reduction in reciprocating weight and allowing the use of high center girts to more rigidly support the bed under impression.

The reversing of the bed is accomplished by means of a crank-pin and block working in a Scotch yoke (Fig. 4). This yoke makes three complete reciprocations to each printing cycle. Fastened to this yoke is an arm carrying a block, and by means of corresponding blocks located on the rack hanger, the bed is controlled during the reverse. As the bed reaches the end of its uniform travel the block on the rack hanger comes into contact with the block on the Scotch yoke, the bed gear leaves the rack, and the slowing down and reversing of the bed takes place. To insure these blocks staying in positive contact, a locking mechanism is used. The reversing of the bed is assisted by air cushions, two at each end.

For the inking of the forms, a pyramid-type inker is used. This inker consists of four form rollers $2^1/_2$ in. in diameter completely covering the maximum-size form, together with three vibrating steel storage rollers, four composition distributing and duct rollers, and two steel riders.

The construction of this inker, together with the method of vibration used, has proved of assistance in the uniform inking of the form, which materially assists the overcoming of such printing troubles as shadows, ghosting, and offsetting.

The ink fountain is of ample capacity, rigidly built, easily adjusted, and so designed that it gives a continuous agitation to the ink supply in the fountain bowl. The inker as a whole is of run-back construction, which makes the entire inking mechanism, including the form rollers, accessible for wash-up and roller adjustment.

The delivery is of cantilever construction, making easier the removal of the printed pile. The sheet is stripped from the second color impression cylinder in the usual manner and is conveyed to the delivery pile by reciprocating finger-carrying tapes (which roll out from under the sheet on the return stroke), delivering the sheet to the pile, where it is jogged by means of side and rear joggers.

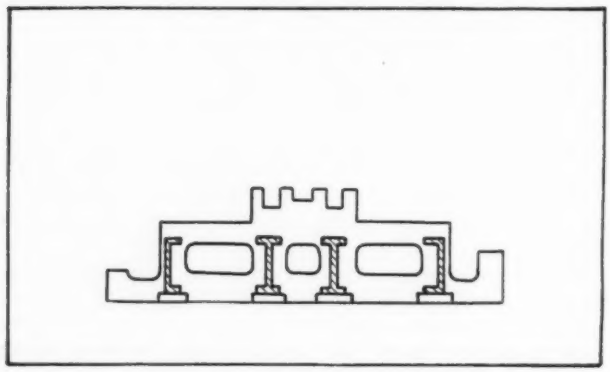


FIG. 1 PRESS FRAME, CENTER, AND END GIRTS

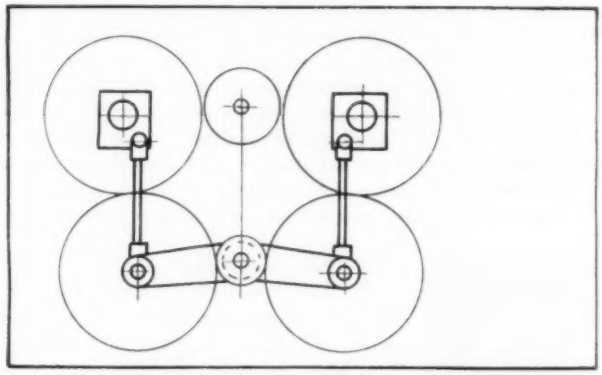


FIG. 3 CYLINDER INTERMEDIATES

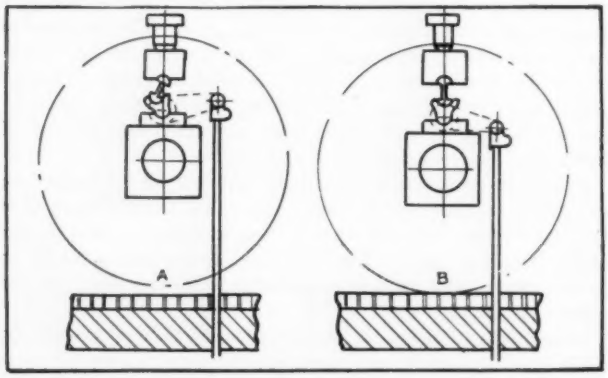


FIG. 2 IMPRESSION MECHANISM—*A*, OFF IMPRESSION; *B*, ON IMPRESSION

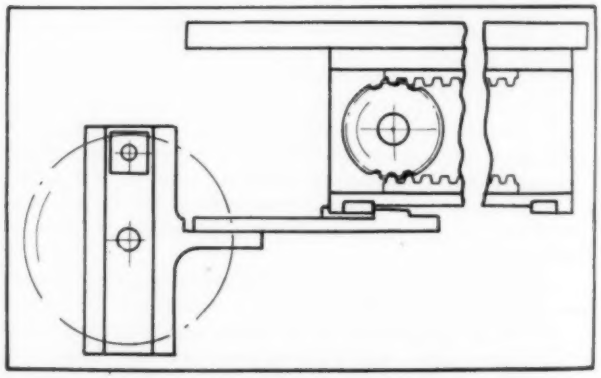


FIG. 4 BED DRIVE AND REVERSE

PI-52-10

Sizes and Tolerances for Metal Fits

Advantages of Standardization for Manufacturing Practice—Controlling Influences and Application to Existing Conditions—Analysis and Reference to the Practice in Other Plants

By C. R. REIMAN,[1] RIDGEWOOD, N. J.

This paper discusses comparisons of metal fits. The matter of working fits being left in many plants largely to the opinion and ability of the workman, the need of standardization in consequence asserts itself as organizations are entitled to records of these matters. The comparisons of the practice of other standards and the analysis that influences the conclusions are given in a simple way. Simplification for better understanding is aimed at, and the need for a standard common practice throughout our industry is recognized. Controlling influences are considered, and various features for which advantages are claimed are stressed. The use of the basic size to under hole system, and the basic shaft are discussed. Different kinds of fits are compared, and the reasons for differentiating between straight shafts and turned studs are given.



THE cause of two mating parts fitting either properly or improperly has been and still is a subject of real interest and one on which many thoughts and suggestions have been offered for discussion. Much of the work by others has been of a more general nature, in which more classifications or kinds of fits have been treated. Unquestionably a great amount of this work has been far more vast than ours, while many of the papers of others have dealt with this subject in a somewhat less extensive scope. All have nevertheless proved valuable contributions to so important a project, the final conclusions and solutions of which will be a boon to those interested in production and manufacture.

The work of the various standards committees and associations, as well as of individuals and concerns, gives evidence of the whole-hearted attempt to clarify and bring into being a practical and easily comprehensible understanding of this matter.

This paper makes no attempt to deal with the subject either as a national and much less as an international solution, but is offered as a contribution in which we give our findings as applied to our work and our methods principally. While it will apply to certain other kinds of machinery bearing a similar classification, we have held this part of it a secondary consideration.

Many good reasons for these attempts at standardization are known, probably not the least among them being the dangerous and costly condition existing in many plants of permitting assemblers to enlarge holes to compensate for oversized companion pieces or to correct inaccurate alignments.

The standardization of sizes by limit is necessary where production schedules and costs are considered. This concerns not only the making of the part itself, but reflects as well into assembly advantages and the replacement problem for service and repair.

Tolerances specified for all studs and shafts and their mating parts should provide for the fits that are required for proper assembly and function. Dimensions giving high and low limits should in all cases be specified on the drawing so that they will be correctly sized where they are machined. A careful check of all assemblies is necessary and the sizes should be chosen to agree with the condition. In order to help make the plan a success and to obtain the best results, all interested should familiarize themselves with the principles of the plan and the importance of working to the blueprint specification. If this practice is followed throughout, there will be but few occasions to use reamers in the assembly departments.

Controlling Influences

Our study is influenced by *the functional requirements of the device, the nature of the work, the quantity, economics, and the available equipment.*

The first of these is of greatest importance, since the rightful existence of the part makes all else possible. The nature of the work to be done on the part ties up closely with its functional requirements, and quite often advantages can be taken of sound and practical engineering to which the design of the part lends all possible favor. Large quantities of course are desirable, but are not always in demand, in which case economics requires full consideration. Available equipment if unsuited to assist readily and properly must be modified or replaced so that full advantage may be derived. Reverting to the functional requirement, the modern high-speed high-grade automatic printing press requires fine accuracy in many of its components, comparable with other devices in the machine and tool building industry, and while parts lots do not run into quantities as large as for some other devices, the need of their fitting properly manifests itself; hence our study of sizes and tolerances.

Reference to the Practice of Others

As a further preliminary, reference to tabulations for running and tight fits as practiced by others was helpful. A comparison of tabulations in a graphical way showing the tendency of leaning to looser or tighter fits is based in a general way on the data available. The following have been consulted:

1 Brown & Sharpe Mfg. Co., L. D. Burlingame, Trans. A.S.M.E., 1910.

2 General Electric Company, L. P. Alford, "Bearings and Their Lubrication," p. 91.

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[1] Special Investigation, Kelly Press Division, American Type Founders Company, Elizabeth, N. J. Mr. Reiman has been in his present connection since 1925, serving with engineering duties principally on special investigation, standardization, and development of new projects. Prior to this, he was Chief Engineer in charge of the Elevator Division, American Machine and Foundry Company, and Assistant Superintendent with E. J. Manville Machine Company, with added duties of engineer on special projects and standardization. Member of A.S.M.E. Sectional Committee on Allowances and Tolerances for Cylindrical Parts and Gages, representing the Printing Press Manufacturers Association.

Contributed by the Printing Industries Division and presented at the Annual Meeting, New York, N. Y., Dec. 1 to 5, 1930, of The American Society of Mechanical Engineers.

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3 Engineering Division Standards, American Machine & Foundry Co.
4 Tentative American Standard, "Tolerances, Allowances, and Gages for Metal Fits," B-4a, 1925.
5 S K F Ball Bearing Co., Bulletin 98-B.

Table 1, under the heading, "Comparison of Clearances With Other Standards," gives their largest and smallest clearance or running fits and has been compiled from the references mentioned. With the exception of General Electric's allowance, all are in the range of our study. The allowances given by them are considerably larger in comparison to the other tabulations, and as their activities are quite diversified, we have no knowledge of their particular application, so we will make no further reference to the General Electric allowances. Figs. 1 to 9, inclusive, deal with comparisons of running fits, each one indicating its particular comparison.

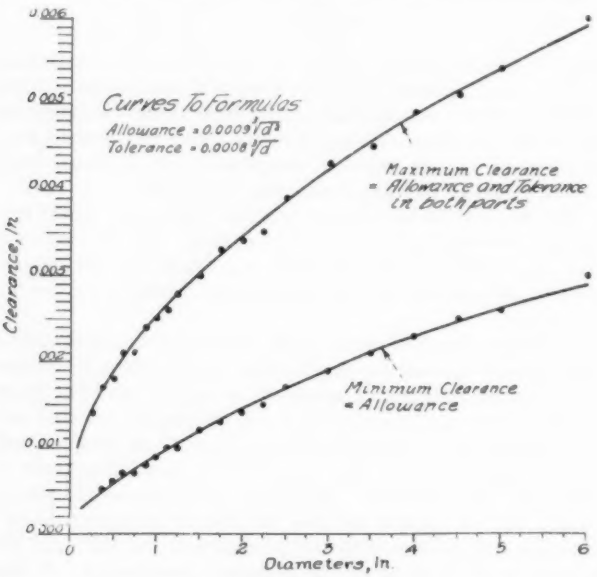


FIG. 1 TENTATIVE AMERICAN STANDARD, B-4A, 1925, CLASS 3, MEDIUM FIT

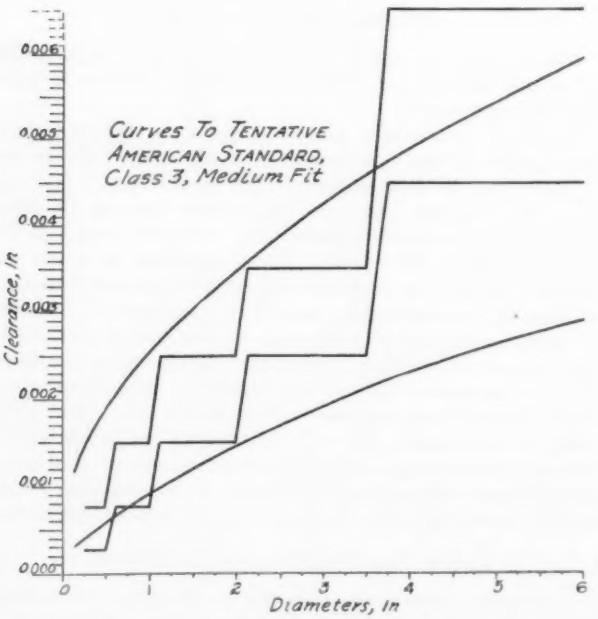


FIG. 2 RUNNING FITS, BROWNE & SHARPE

TABLE 1 COMPARISON OF CLEARANCES WITH OTHER STANDARDS

Inch	Brown & Sharpe[1]	General Electric[2]	Amer. M. & F.[3]	A.S.A.[4]
1/4	0.00025–0.00075	.....	0.0005–0.00125	0.0004–0.0014
3/8	0.00025–0.00075	0.002–0.0035	0.0005–0.00125	0.0005–0.0017
1/2	0.00025–0.00075	0.002–0.0035	0.0005–0.00125	0.0006–0.0018
5/8	0.00075–0.0015	0.002–0.0035	0.00075–0.00175	0.0007–0.0021
3/4	0.00075–0.0015	0.002–0.0035	0.00075–0.00175	0.0007–0.0021
7/8	0.00075–0.0015	0.002–0.0035	0.00075–0.00175	0.0008–0.0024
1	0.00075–0.0015	0.002–0.0035	0.00075–0.00175	0.0009–0.0025
1 1/8	0.0015–0.0025		0.00125–0.0025	0.001–0.0026
1 1/4	0.0015–0.0025	0.003–0.0045	0.00125–0.0025	0.001–0.0028
1 3/8	0.0015–0.0025		0.00125–0.0025	0.001–0.0028
1 1/2	0.0015–0.0025	0.003–0.0045	0.00125–0.0025	0.0012–0.003
1 5/8	0.0015–0.0025		0.002–0.0035	0.0012–0.003
1 3/4	0.0015–0.0025	0.003–0.0045	0.002–0.0035	0.0013–0.0033
1 7/8	0.0015–0.0025		0.002–0.0035	0.0013–0.0033
2	0.0015–0.0025	0.003–0.0045	0.002–0.0035	0.0014–0.0034
2 1/8	0.0025–0.0035		0.002–0.004	0.0015–0.0035
2 1/4	0.0025–0.0035	0.003–0.0045	0.002–0.004	0.0015–0.0035
2 3/8	0.0025–0.0035		0.002–0.004	0.0015–0.0035
2 1/2	0.0025–0.0035	0.003–0.0045	0.002–0.004	0.0017–0.0039
2 3/4	0.0025–0.0035	0.004–0.0065	Nothing given beyond 2 1/2 in.	0.0017–0.0039
3	0.0025–0.0035	0.004–0.0065		0.0019–0.0043
3 1/4	0.0025–0.0035			0.0019–0.0043
3 1/2	0.0025–0.0035	0.004–0.007		0.0021–0.0045
3 3/4	0.0035–0.005			0.0021–0.0045
4	0.0035–0.005	0.005–0.008		0.0023–0.0049
4 1/4	0.0035–0.005			0.0023–0.0049
4 1/2	0.0035–0.005	0.005–0.008		0.0025–0.0051
4 3/4	0.0035–0.005			0.0025–0.0051
5	0.0035–0.005	0.006–0.009		0.0026–0.0054
5 1/4	0.0035–0.005			0.0026–0.0054
5 1/2	0.0035–0.005	0.007–0.010		0.0026–0.0054
5 3/4	0.0035–0.005			0.0026–0.0054
6	0.0035–0.005	0.009–0.012		0.003–0.006

[1] L. D. Burlingame, Trans. A.S.M.E., 1910.
[2] "Bearings and Their Lubrication," L. P. Alford.
[3] Eng. Divn. Standards, A. M. & F. Co.
[4] Tentative American Standards, Class 3, Medium Fit, "Tolerances, Allowances, and Gages for Metal Fits," B-4a, 1925.

The graph, Fig. 1, compares the Tentative American Standard, Class 3, Medium Fit, tabulations as given in the standard. The horizontal gives nominal diameters up to 6 in., and the vertical clearances in ten-thousandths of an inch. The curves are developed from the formulas given, the lower representing allowance or minimum clearance, while the upper represents the maximum clearance, or the allowance plus tolerance for both mating parts. The space between the upper and lower curves is the desired field in which the tabulations for the various sizes should fall to produce the preferred condition. The various points on or near the curves are the positions that the tabulated figures indicate. Slight variations over or under the curves occur, as the figures are given to four decimals only. These differences are negligible, since the amounts are smaller than are usually employed in practice. It does show, however, that the committee which established this standard has been generous in its allotment of the number of steps. This was because of the desire to follow the guiding curves as closely as possible.

On the graphs that follow in this discussion the various steps are fewer, which is intended to simplify the practice. Greater variations from the true line, however, will occur because of this, but it still is considered conservative practice.

In Fig. 2, which compares Brown & Sharpe's running fit for ordinary speeds, we again use the Tentative American Standard, Class 3, curve. In this case their step-up occurs less frequently than in our first case, they having but five steps for the range up to 6 in. Their allowances are indicated by the lower range of steps up to the 1/2 and 1 in., which sizes are somewhat below the comparing curve, while at 3 1/2 in. their maximum clearance takes a decided jump upward, being looser than the greatest limit for this diameter allowable by the curve. This, however, is for the extreme limit. The mean of the minimum and maximum clearance is fair to the curve. The intermediate portion is comfortably well within the desired field. An intermediate step between this and the 6 in. diameter would have

shown better uniformity. On a general average the tendency is toward greater looseness.

Fig. 3 shows comparisons of the practice of the American Machine and Foundry Company, on machines of similar class, with the Tentative American Standard, Class 3, curves. The data available here are somewhat meager as no figures beyond the $2^1/_2$ in. diameter are given. On the allowance steps, four are used, while the upper or maximum clearance has five. The tendency in this case up to the $1^1/_2$-in. size is to greater tightness, as that part of the steps shows below the curves, while from $1^3/_4$ in., the leaning is toward greater looseness. This is of course on the extremes in both cases. Their mean average would fall nicely within the desired field. In completing the steps to the 6 in. diameter we probably would again have numerous changing points according to the set-up on the available figures. No further reference, however, need be made to this as it would merely be conjecture.

Fig. 4 compares maximum and minimum clearance of Kelly

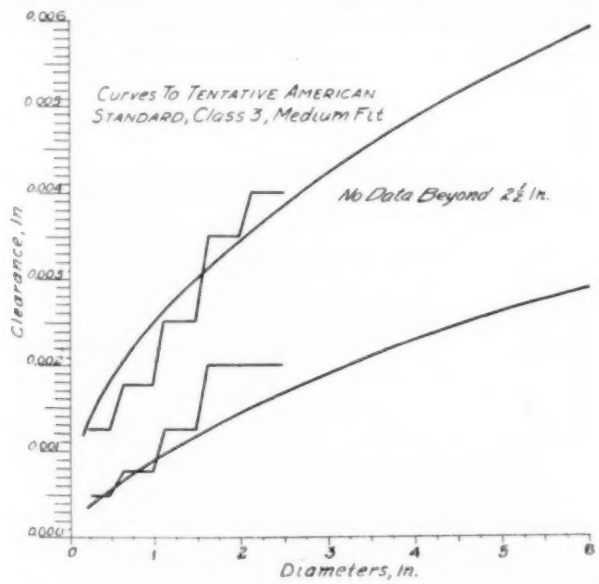


Fig. 3 Running Fits, American Machine and Foundry Company, Engineering Division Standards

Press practice as enumerated in Tables 2 and 3, with the guiding curves, which are again taken from the Tentative American Standard, Class 3. There are five steps used for the range up to 6 in. The indications by this comparison show a decided leaning toward closer fitting than those of the standard. The lower steps, which represents minimum allowance, fall, on an average, below the given curve, while the upper steps, representing allowances plus tolerances for both mating parts, are considerably below the upper curve. On the 6 in. diameter this difference is measured as being 0.0014 in. The two causes that bring this tendency to a lesser looseness are that the allowance is less and the tolerances are held closer. In reality it is nothing more than a finer or closer fit than that used by the curve. When fits are made closer, allowances and tolerances are reduced accordingly. We find it good practice to fit rather closely as there are many components that demand a considerably higher degree of accuracy than the average running fit. After the exercising period, which consists of running the press idle at normal speeds for 50,000 or more impressions, the stiffness caused by accumulations of slight irregularities wears off, with a result of a nice fitting condition rather than that of one already half-worn out by having the fits rather free to begin with. We will find by comparing some of the following graphs how this class of fits averages with some of the other known classes.

In Fig. 5 the steps representing the minimum and maximum clearance for running fits by Kelly Press are the same as on Fig. 4 and coincide with the figures of Tables 2 and 3. The curves, however, differ, they having been constructed to revised formulas. For the lower or allowance curve, we use a constant 0.0008 in place of 0.0009, as used in the Tentative

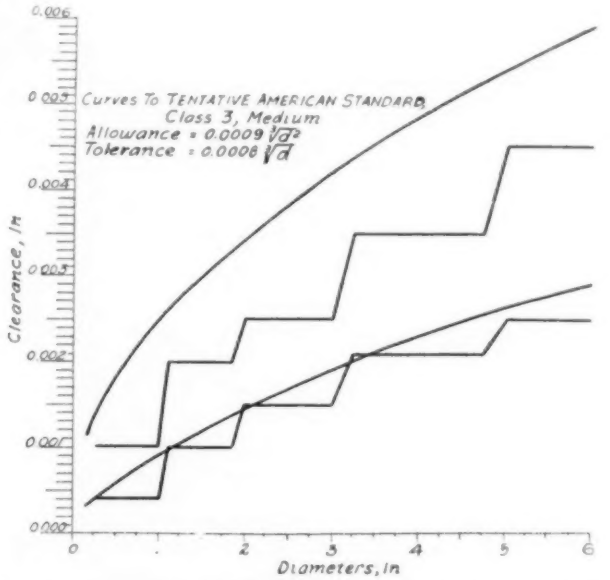


Fig. 4 Running Fits, Kelly Press Division, American Type Founders Company

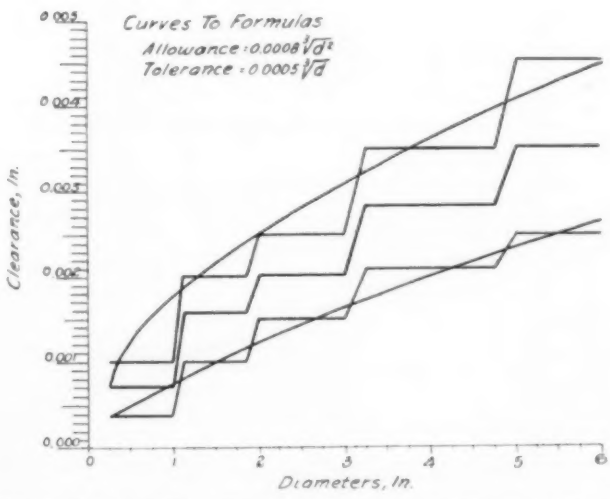


Fig. 5 Running Fits, Kelly Press Division, American Type Founders Company

American Standard, Class 3. The tolerance is based on substituting constant 0.0005 instead of 0.0008, as used in the same standard. While this results in smaller tolerances and less clearance, we are still within conservative practice for tolerances, the small sizes being to 0.0003 and the largest to 0.001. The intermediate range from $1^1/_8$ to $4^3/_4$ in., in which much of the work occurs, has tolerances of 0.0005 and 0.0007, the tolerances for both mating parts being the same. The averages of the

steps which represent the extremes for maximum and minimum clearance compared with the guiding curves are fair, the mean average of the two being favorable to the desired field.

Fig. 6 is slightly more complex than those previously referred to. In this case, we deal with the S K F recommendations for Housing Mounting Fits, comparing them with the Tentative American Standard, Class 3, and the running-fit curve of Kelly Press constructed from the revised formula. We are all quite familiar with the kind of fit usually employed when mounting the ball bearing into its housing. S K F refers to it as a

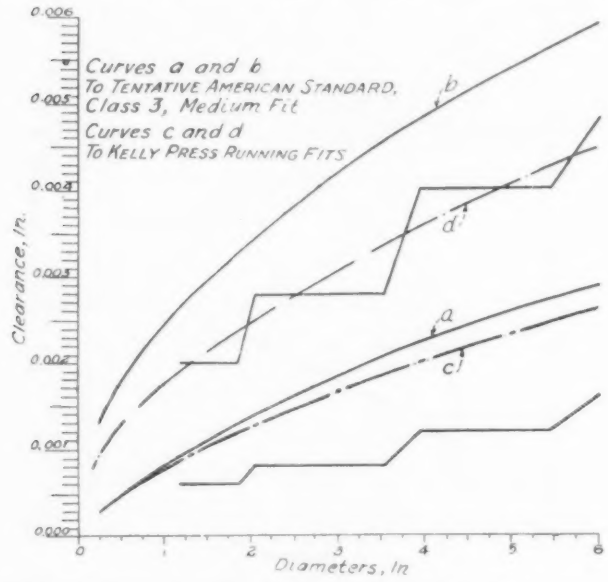


Fig. 6 Housing Mounting Fit Practice, S K F Industries

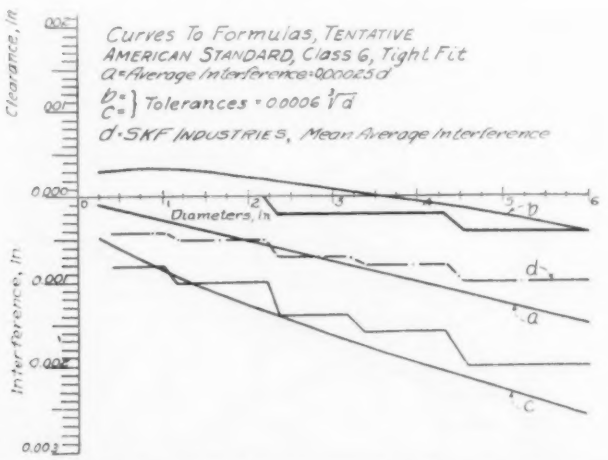


Fig. 7 Press Fits, S K F Industries, Ball-Bearing Mounting on Shafts

sucking fit. Our purpose in making the comparison in this way is to demonstrate an intermediate condition between the Tentative American Standard, Class 3, fit, which is looser than that of Kelly Press for running fits, and the Housing Mounting Fit of S K F, which is tighter. While the Housing Mounting Fit allows the outer race to creep or slide for compensation, it certainly would not be used for a running condition.

The steps in the graph agree with the minimum and maximum clearance by S K F given in millimeter sizes in their bulletin. (For our study we have transposed these sizes into inches for uniformity with our diameter scale, omitting the millimeter graduations.) Having visualized the Housing Mounting Fit, we compare it with the curves *a* and *b*, which again represent the minimum and maximum clearances of the Tentative American Standard, Class 3, and find an expression of a considerably tighter fit, while the fit obtained by the Kelly Press running-fit curves shows looser than the steps for S K F and slightly tighter than the Tentative American Standard, Class 3, curves *a* and *b*. In this way the intermediate class is easily visualized. In summary, the Kelly Press running fit is looser than the S K F Housing Mounting Fit practice, but tighter than the Tentative American Standard, Class 3, fit.

This concludes our discussion and comparisons on running fits, and before entering on that part of the subject dealing with other kinds of fits, we mention that, to avoid complication as much as is possible, only three kinds of fits were chosen. These are the running fits, which have been discussed, and the force and wring fits which are to follow.

The establishment of a standard for general practice throughout the industry must of necessity provide for that number of

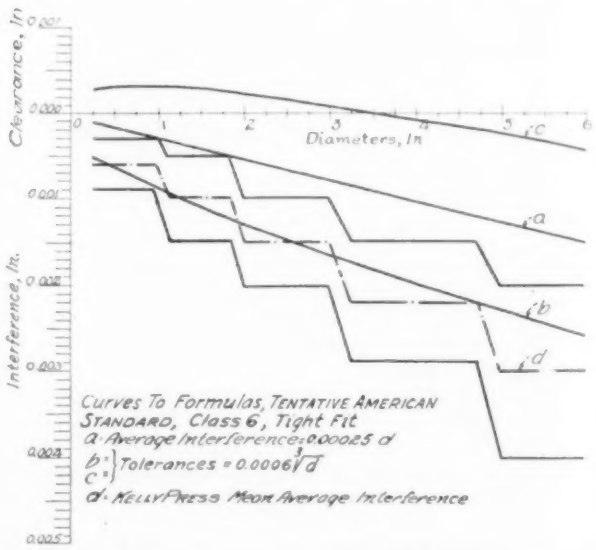


Fig. 8 Force Fits, Selective, Kelly Press Division, American Type Founders Company

classifications that are required by the various branches. As we are dealing solely with our own part of the problem, we have chosen but three. The American Tentative Standard gives eight, and from what has been demonstrated in the foregoing it is evident that more than that number of classifications should be available.

The German National Standard—generally referred to as the DIN system of fits—we understand, gives 22 fits, specified both in the "basic hole" and the "basic shaft" system. This raises the question whether the existing Tentative American Standard should be supplemented by a "basic shaft" system.

We have found such a provision desirable for our work, and undoubtedly many others find the same.

This part of the subject, however, may better be left for discussion under another heading, but as our arrangement uses this feature we find it necessary to mention the need.

Force Fits

Before taking up the Kelly Press practice on force fits, we refer to the S K F fits of ball-bearing mounting on shafts as

compared to the Tentative American Standard, Class 6, tight fit. Fig. 7 makes the comparison in a graphical way. As we have both interference and possible clearance to contend with, the graph is divided. The upper part (above the zero) indicates clearance, as before, and the lower section (below the zero) interference. The values for the graduations remain the same, and the millimeter sizes have again been transposed into inches. The line *a* gives the mean average interference up to 6 in., and is based on the formula average interference = 0.00025 *d* as given in the standard. Curves *b* and *c* represent the loosest and tightest fit, respectively, and are also based on the standard.

The steps show the practice of S K F for the high and low limit, as given in their bulletin, while the intermediate step *d* is the mean average for their practice. A study of the graph discloses the reason for the necessity of the fit being selective according to the Tentative American Standard, as part of curve *b*, up to about $3^1/_2$ in. diameter, falls within the clearance zone. Tight fits can have no clearance, of course, and selection is therefore necessary.

The upper step, representing minimum interference for S K F, shows zero interference for part of its length, but by this

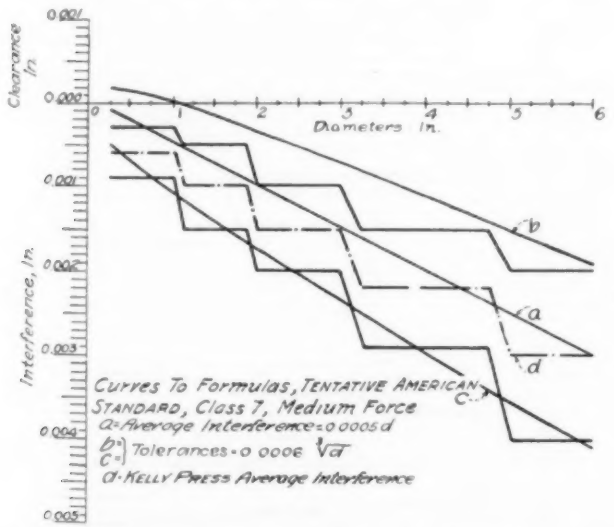


Fig. 9 Force Fits, Selective, Kelly Press Division, American Type Founders Company

arrangement fits need not necessarily be selective, though this may be desirable for this work. If the parts are rugged enough to withstand the pressures, no selection should be necessary. The S K F practice, according to the comparison, fits nicely within the American Standard curves, being if anything slightly looser throughout an average and never loose enough to give actual clearance.

Fig. 8 compares the Kelly Press force fits, the figures for which are given in Tables 2 and 3, with the Tentative American Standard, Class 6, tight fit. The line *a* represents the average interference, and the curves *b* and *c* the tightest and loosest fits. All are constructed from the formulas of the standard, as in the preceding case on Fig. 7. The possibility of clearance is again in evidence as before.

The various steps show the loosest and tightest fit according to our tabulations, and throughout there is a decided leaning toward a tighter fit than allowed by the Class 6 curves.

Fig. 9 shows the average interference line and the minimum and maximum interference curves *b* and *c*, according to the Tentative American Standard, Class 7, Medium Force Fit. The various steps are again taken from Tables 2 and 3 of the Kelly Press practice, with the mean average shown by line *d*. A possible clearance up to $1^1/_4$ in. is again in evidence on the minimum curve of the Standard, which would again indicate the necessity of selection. This graph shows the Kelly Press force fit to be slightly tighter than the medium force fit of Class 7. Otherwise the agreement is good.

Fig. 10 compares Kelly Press force fit with the Tentative American Standard, Class 8, Heavy Force or Shrink Fit. The curves and steps representing their factors are as before. The

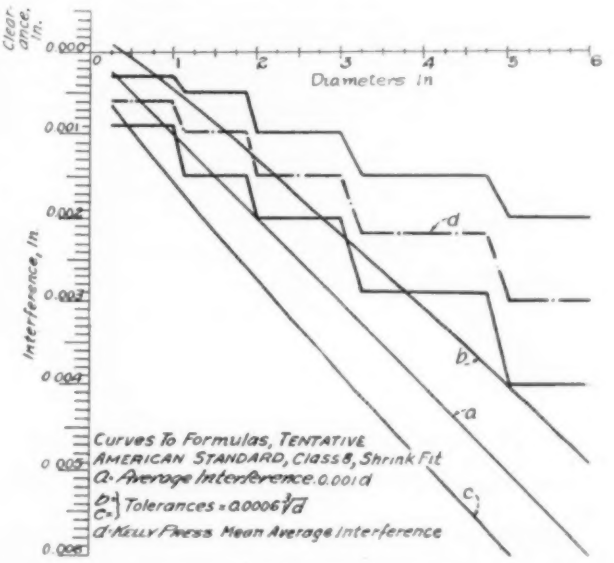


Fig. 10 Force Fits, Selective, Kelly Press Division, American Type Founders Company

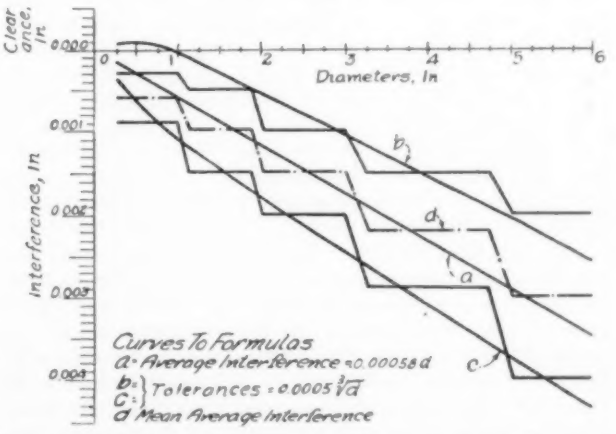


Fig. 11 Force Fits, Selective, Kelly Press Division, American Type Founders Company

curves show the Standard to provide for considerably more tightness than in our case. The purpose of making this comparison is to show that there is a vast difference between these two classifications; otherwise it serves no purpose.

Fig. 11 gives both curves and steps to Kelly Press practice for force fits. The curves, however, have been reconstructed from revised formulas. For average interference we have 0.00058 *d* as compared to 0.0005 *d*, used in Class 7. The tolerance is closer and is based on 0.0005 $\sqrt[3]{d}$ in place of 0.0006 $\sqrt[3]{d}$, as used in the same class.

While the curves are quite similar, the resulting fit is tighter than that of the medium force of Class 7 and not nearly so tight as that of the heavy force fit of Class 8. No effort is made to control these fits by designation of tonnage pressure, as our factors deal only with average work in this class.

Wring Fits

This section of our work requires closer study because of a greater exactness required for this kind of a fit than either the running or force class. Any attempt at strict interchangeability

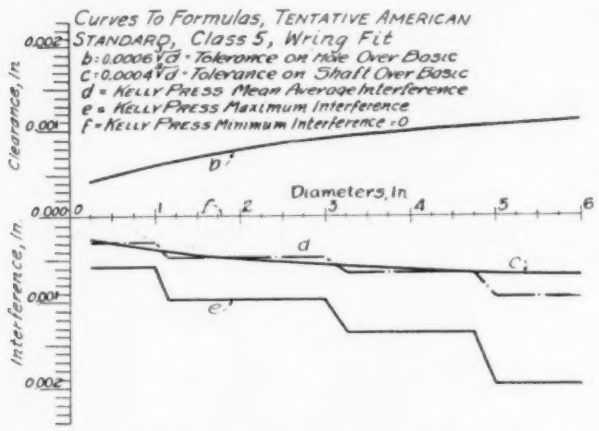


Fig. 12 Wring Fits, Selective, Kelly Press Division

is passed on, as manufacturing costs become prohibitive in our case.

Generally speaking, we apply the term wring fit in the manner of two parts going together by slight exertion in pushing and twisting one part onto or into another.

Fig. 12 shows curve *b* representing the loosest fit and curve *c* the tightest according to the Tentative American Standard, Class 5, Wring Fit. Curve *b* shows clearance while Curve *c* indicates interference. The mean interference according to the tabulations in the Standard is zero, and the possibilities of a tight or loose fit are governed by tolerance and selection. Curve *b* also represents the tolerance on the hole over basic, and curve *c* the tolerance on the shaft over basic. Both are constructed from the values given in the Standard. Kelly Press practice has a minimum interference of zero, instead of clearance as in the Standard, represented by line *f*. The step *d* is mean and *e* represents the tightest fit. In either case, the classification becomes purely selective, perhaps a little more so in the Standard because of the possibility of clearance. In the case of the Kelly Press practice, when selection has been exhausted and the extremes of the sizes on the remaining parts cause too tight a fit, recourse to resizing, usually by the ball sizing method, is resorted to. This works out in a practical and convenient way, since the leaning of fits is to the tight side. In the case of too great looseness possible with practice of the Standard, no recourse is available except to hold the parts for the next lot or possibly for salvage.

Fig. 13 is a composite in which the lower part below the zero line compares the S K F press fits on shafts with curve *c* of the Tentative American Standard, Class 5, Wring Fit, curve *c* showing the interference value of that class. The steps represent the values as given by S K F for the tightest and loosest fits. The intermediate step *d* is the mean of these. The tendency here is toward a tighter fit of the ball bearing on the shaft than on the interference curve *c* of the Class 5, Wring Fit, of the Standard would provide for.

The upper section above the zero line compares the S K F recommendations for Housing Mounting Fits for the outer ring of ball bearings in their mounting with curve *b* of the Class 5, Wring Fit, of the Tentative American Standard. Curve *b* shows the clearance obtainable in Class 5. The steps represent the sizes given by S K F for the tightest and loosest fits, the intermediate step *e* being the mean.

In summary, the step *d* is the mean average interference on the shaft mounting, and the step *e* the mean average clearance for the housing mounting of S K F for ball-bearing practice.

These various steps, when compared with the interference and clearance curves of Class 5, Wring Fit, of the Standard, show the difference in the three types of fits. The lower section shows greater tightness and the upper one more looseness.

The comparison in Fig. 14 is between S K F practice for Housing Mounting Fit and the Tentative American Standard, Class 4, Snug Fit. The curve *a* shows the maximum clearance of this class, while the minimum clearance is zero. Step *b* is the S K F mean average clearance, while the upper and lower steps give the loosest and tightest fit, respectively, for their practice. The graph shows the Housing Mounting Fit to be looser than the

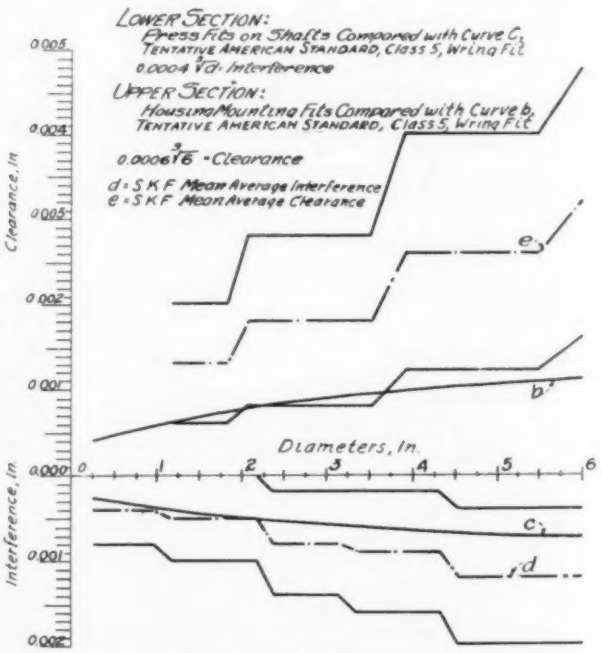


Fig. 13 S K F Industries

Class 4, Snug Fit, of the Standard. As no data are given below 30 mm., no comparison is available below that size.

Fig. 15 makes a comparison of the Kelly Press Wring Fit with the Tentative American Standard, Class 6, Tight Fit, the line *a* representing the average interference and curves *b* and *c* the loosest and tightest fits according to the Standard. Curve *b* again shows clearance for part of its length. From about $3\frac{1}{2}$ in. upward its range is from zero to interference. In the Kelly Press steps we have zero as minimum interference, the greatest interference being shown by the lower steps *d*, while the mean is shown as intermediate *e* between zero and the maximum tightness *d*.

The average tendency of the Kelly Press Wring Fit is for less tightness than shown by the Class 6, Tight Fit, of the Standard, and even while this lesser tightness is in evidence, our wring fit is again on the safe side for further resizing when selection has

been exhausted. There being no indication of possible clearance, we again find this feature desirable, particularly so because of the small quantities of parts sometimes in work.

This concludes our discussion on the various comparisons, on which analysis the tabulations for the three kinds of fits have been prepared. We appreciate that with only three kinds of fits available, some special cases exist where certain unusual fits are necessary, which require other allowances or tolerances than those given. In such cases they arbitrarily become special and are treated as such by reference to precedent or other accepted standard practice.

No Oversize Holes

It will be noticed that, in all cases, holes are basic to under or smaller. There are desirable and practical reasons for this.

We have the three classes of fits for both the basic hole and the basic shaft standards, and deal with a standard hole (basic to under) for all cases of female parts used with studs or short length diameters (whether running, wring, or force fits) and running fits on straight shafts, all without exception. This provides for four major cases out of six, the remaining two being

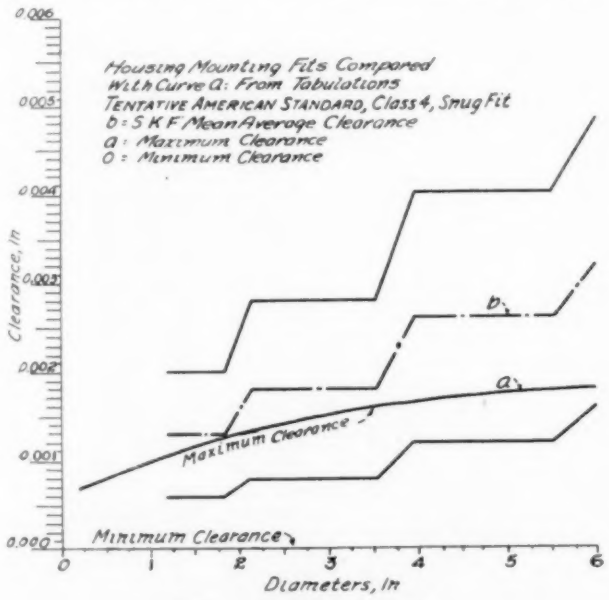


Fig. 14 S K F Industries

wring and force fits on straight shafts and which are in a minority in so far as number goes. The cases of the latter two are treated by varying the hole size as the shaft is standard (basic to under) where straight shafts are involved.

Plug gages do not increase in size through use, and when worn have no further value except by possible salvage. When worn and undetected, parts gaged by them are small and are subject to further resizing, which additional operation must be considered because of economics. This condition is probable when holes are basic to over. Where hole sizes are varied to produce different classes of fits, the variety of sizes of gages becomes more numerous, whereas the fewer number of classifications for hole sizes requires a correspondingly less variety of sizes for the gages. Standard gages by Kelly practice when worn below tolerance are resizes for the wring or force fit class of the shaft standard. The hole for these being smaller than basic to under are the only cases where the hole is *exceptional to standard.*[2]

[2] For our practice, standard holes are basic to under.

Reamers unless ordered to specification must be sized to produce given diameters. Commercial or catalog reamers, as they are sometimes called, produce sizes over standard, some of this oversize being added to prolong the life of the reamer. This practice is distinctly an encroachment by the reamer manufacturers on the rights of the user and compels acceptance of sizes for holes up to and sometimes over the largest limit. Such holes when gaged by standard plugs show a decided leaning to being too large and suggest unsatisfactory work, as the hole is too loose on the gage.

Then, too, we have materials with their varying densities to

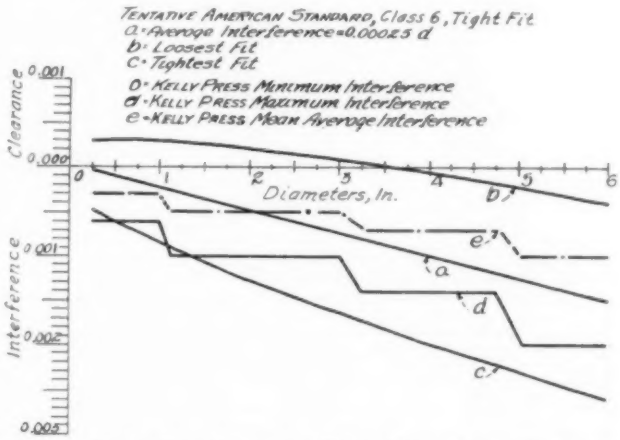


Fig. 15 Wring Fits, Selective, Kelly Press Division, American Type Founders Company

consider, as well as whether the reaming is to be done wet or dry. These factors have a vast influence on determining the cutting sizes of reamers, and unless the specifications covering are clear and complete, the result is negative. When a hole is gaged by plug, it should fit to be called standard, and it is not standard when free on a standard plug. This is often the result when the influences pertinent to practice are ignored or neglected.

Another factor influencing and favoring the basic to under standard for the hole is the use of commercial bars of both the ground and the cold-drawn quality. Such bars generally do not run over the nominal size, but basic to under, which is advantageous when holes are made basic to under. Bars or shafts whose sizes run over nominal usually are burdened with an extra cost because of the special handling involved.

Studs and Short Length Diameters

Table 2 applies to studs and short length diameters, giving the maximum and minimum dimensions of both the male and female member from $^1/_4$ to 6 in. For this group, the maximum hole diameter is basic, and the tolerance is applied so the hole will be basic to under. While figures are given that establish tolerances in tenths of thousands, they are accepted as an interpretation of a wring fit on the standard plug under manufacturing conditions. The tolerances and resulting clearances or interferences are given as a matter of convenience, it being intended that only the high and low limit be given on the drawing.

This table applies to diameters in which no association with straight shafts is involved as it is used only for studs and such diameters that would not be classified under straight shafts and their members.

In this case, *the hole size is common* to all three kinds of fits while the stud size changes agreeable to the kind of fit.

Table 3 applies to *ground straight shafts only* and is not used for commercial cold-drawn or cold-rolled bars or for studs or short length diameters. Diameters from $^1/_4$ to 3 in. are given for this group, the maximum of the hole for running fits only is basic. The shaft diameter is established to produce a running fit, using the hole size as basic to under, after which the hole sizes for the wring and force fits are determined from the shaft.

In this group the *shaft size is common* to all three kinds of holes, for the running, wring, or force fit; while the hole size from standard size to minimum in our table, the diameter of the bar not to fall below the low limit. Should the stock run to basic which is over our high limit, it would be slightly large, but could easily be reduced.

New Mating Members for Repairs on Old Size Shafts

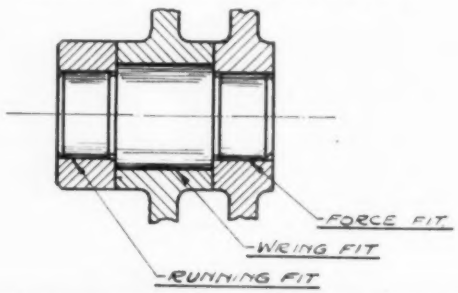
Part of our old arrangement involved the use of shafts that were made to an oversize standard and with which certain existing machines still in operation are equipped. The repair changes for the wring and force fit only. Both columns for hole sizes under wring and force fits in this table give smaller diameters than the basic to under hole for running fits. Since no holes over standard are permissible and with the shaft fitted to basic to under holes for running fits, it follows that the tighter fits of the wring or force kind require smaller holes.

The tolerances and the resulting clearances and interferences are identical with those established for studs and short length diameters.

With the shaft diameters established in this manner, it is possible to purchase selected stock or commercial ground bars and replacement problem is involved because of this. When furnishing members or parts for repairs for such machines, the holes in the replacement parts according to the new standard would be small and consequently safe, as the shaft, being to the old standard, is large compared to the shaft of this standard. It might therefore be necessary to scrape or resize the hole slightly to produce the desired fit.

Shafts and studs in service do not increase in size through use, and we find it desirable to leave holes in such repair parts this way, as servicing will be favored and the necessity of carrying parts having special holes in stock will be eliminated.

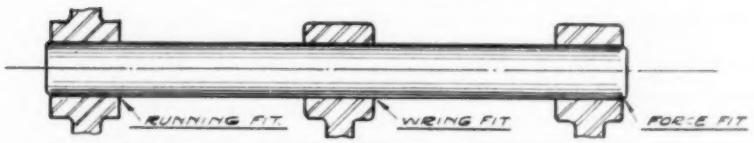
TABLE 2 TOLERANCES AND SIZES FOR FITS



T = TOLERANCE GIVEN IN TENTHS OF THOUSANDTHS

SIZE	DIAMETERS STANDARD HOLE MAX = BASIC		STUDS AND GROUND DIAMETERS NOT USED FOR STRAIGHT SHAFTS T	RUNNING FIT	T	WRING FIT	T	FORCE FIT	T	RESULTING FITS RUNNING FIT CLEARANCE		WRING FIT INTERFERENCE		FORCE FIT INTERFERENCE	
1/4	.250	.2497	3	.249	.2493	3	.2503	.2500	3	.2503	.2506	3	.0004	.001	.0000	.0006	.0003	.0009
3/8	.375	.3747	3	.374	.3743	3	.3753	.3750	3	.3753	.3756	3	.0004	.001	.0000	.0006	.0003	.0009
1/2	.500	.4997	3	.499	.4993	3	.5003	.5000	3	.5003	.5006	3	.0004	.001	.0000	.0006	.0003	.0009
5/8	.625	.6247	3	.624	.6243	3	.6253	.6250	3	.6253	.6256	3	.0004	.001	.0000	.0006	.0003	.0009
3/4	.750	.7497	3	.749	.7493	3	.7503	.7500	3	.7503	.7506	3	.0004	.001	.0000	.0006	.0003	.0009
7/8	.875	.8747	3	.874	.8743	3	.8753	.8750	3	.8753	.8756	3	.0004	.001	.0000	.0006	.0003	.0009
1 —	1.000	.9997	3	.999	.9993	3	1.0003	1.0000	3	1.0003	1.0006	3	.0004	.001	.0000	.0006	.0003	.0009
1 1/8	1.125	1.1245	5	1.123	1.1235	5	1.1255	1.1250	5	1.1255	1.1260	5	.0010	.002	.0000	.001	.0005	.0015
1 1/4	1.250	1.2495	5	1.248	1.2485	5	1.2505	1.2500	5	1.2505	1.2510	5	.0010	.002	.0000	.001	.0005	.0015
1 3/8	1.375	1.3745	5	1.373	1.3735	5	1.3755	1.3750	5	1.3755	1.3760	5	.0010	.002	.0000	.001	.0005	.0015
1 1/2	1.500	1.4995	5	1.498	1.4985	5	1.5005	1.5000	5	1.5005	1.5010	5	.0010	.002	.0000	.001	.0005	.0015
1 5/8	1.625	1.6245	5	1.623	1.6236	5	1.6255	1.6250	5	1.6255	1.6260	5	.0010	.002	.0000	.001	.0005	.0015
1 3/4	1.750	1.7495	5	1.748	1.7486	5	1.7505	1.7500	5	1.7505	1.7510	5	.0010	.002	.0000	.001	.0005	.0015
1 7/8	1.875	1.8745	5	1.873	1.8735	5	1.8755	1.8750	5	1.8755	1.8760	5	.0010	.002	.0000	.001	.0005	.0015
2 —	2.000	1.9995	5	1.9975	1.998	5	2.0005	2.0000	5	2.0010	2.0015	5	.0015	.0025	.0000	.001	.0010	.0020
2 1/8	2.125	2.1245	5	2.1225	2.123	5	2.1255	2.1250	5	2.1260	2.1265	5	.0015	.0025	.0000	.001	.0010	.0020
2 1/4	2.250	2.2495	5	2.2475	2.248	5	2.2505	2.2500	5	2.2510	2.2515	5	.0015	.0025	.0000	.001	.0010	.0020
2 3/8	2.375	2.3745	5	2.3725	2.373	5	2.3755	2.3750	5	2.3760	2.3765	5	.0015	.0025	.0000	.001	.0010	.0020
2 1/2	2.500	2.4995	5	2.4975	2.498	5	2.5005	2.5000	5	2.5010	2.5015	5	.0015	.0025	.0000	.001	.0010	.0020
2 3/4	2.750	2.7495	5	2.7475	2.748	5	2.7505	2.7500	5	2.7510	2.7515	5	.0015	.0025	.0000	.001	.0010	.0020
3 —	3.000	2.9995	5	2.9975	2.998	5	3.0005	3.0000	5	3.0010	3.0015	5	.0015	.0025	.0000	.001	.0010	.0020
3 1/4	3.250	3.2493	7	3.2465	3.2472	7	3.2507	3.2500	7	3.2515	3.2522	7	.0021	.0035	.0000	.0014	.0015	.0029
3 1/2	3.500	3.4993	7	3.4965	3.4972	7	3.5007	3.5000	7	3.5015	3.5022	7	.0021	.0035	.0000	.0014	.0015	.0029
3 3/4	3.750	3.7493	7	3.7465	3.7472	7	3.7507	3.7500	7	3.7515	3.7522	7	.0021	.0035	.0000	.0014	.0015	.0029
4 —	4.000	3.9993	7	3.9965	3.9972	7	4.0007	4.0000	7	4.0015	4.0022	7	.0021	.0035	.0000	.0014	.0015	.0029
4 1/4	4.250	4.2493	7	4.2465	4.2472	7	4.2507	4.2500	7	4.2515	4.2522	7	.0021	.0035	.0000	.0014	.0015	.0029
4 1/2	4.500	4.4993	7	4.4965	4.4972	7	4.5007	4.5000	7	4.5015	4.5022	7	.0021	.0035	.0000	.0014	.0015	.0029
4 3/4	4.750	4.7493	7	4.7465	4.7472	7	4.7507	4.7500	7	4.7515	4.7522	7	.0021	.0035	.0000	.0014	.0015	.0029
5 —	5.000	4.999	10	4.9955	4.9965	10	5.0010	5.0000	10	5.0020	5.0030	10	.0025	.0045	.0000	.002	.0020	.0040
5 1/4	5.250	5.249	10	5.2455	5.2465	10	5.2510	5.2500	10	5.2520	5.2530	10	.0025	.0045	.0000	.002	.0020	.0040
5 1/2	5.500	5.499	10	5.4955	5.4965	10	5.5010	5.5000	10	5.5020	5.5030	10	.0025	.0045	.0000	.002	.0020	.0040
5 3/4	5.750	5.749	10	5.7455	5.7465	10	5.7510	5.7500	10	5.7520	5.7530	10	.0025	.0045	.0000	.002	.0020	.0040
6 —	6.000	5.999	10	5.9955	5.9965	10	6.0010	6.0000	10	6.0020	6.0030	10	.0025	.0045	.0000	.002	.0020	.0040

TABLE 3 TOLERANCES AND SIZES FOR FITS

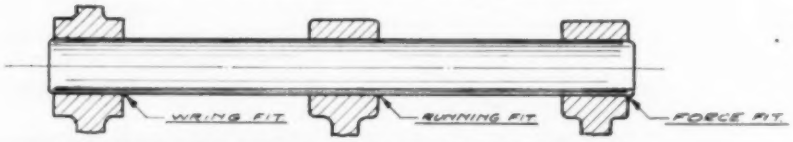


GROUND SHAFTS FOR TIGHT AND LOOSE FITTING MEMBERS IN WHICH SHAFT DIAMETER IS UNIFORM AND HOLE SIZES ARE BASIC AND UNDER SIZE

T=TOLERANCE GIVEN IN TENTHS OF THOUSANDTHS.

SIZE	SHAFT DIAMETERS	T	HOLE SIZES FOR GROUND SHAFTS ONLY. NOT USED FOR STUDS OR COMM. COLD DRAWN BARS. RUNNING FIT HOLES STANDARD	T	WRING FIT HOLES EXCEPTIONAL TO STANDARD	T	FORCE FIT	T	RESULTING FITS: RUNNING FIT CLEARANCE	WRING FIT INTERFERENCE	FORCE FIT INTERFERENCE
1/4	.2493 .249	3	.250 .2497	3	.2490 .2487	3	.2484 .2487	3	.0004 .001	.0000 .0006	.0003 .0009
3/8	.3743 .374	3	.375 .3747	3	.3740 .3737	3	.3734 .3737	3	.0004 .001	.0000 .0006	.0003 .0009
1/2	.4993 .499	3	.500 .4997	3	.4990 .4987	3	.4984 .4987	3	.0004 .001	.0000 .0006	.0003 .0009
5/8	.6243 .624	3	.625 .6247	3	.6240 .6237	3	.6234 .6237	3	.0004 .001	.0000 .0006	.0003 .0009
3/4	.7493 .749	3	.750 .7497	3	.7490 .7487	3	.7484 .7487	3	.0004 .001	.0000 .0006	.0003 .0009
7/8	.8743 .874	3	.875 .8747	3	.8740 .8737	3	.8734 .8737	3	.0004 .001	.0000 .0006	.0003 .0009
1 —	.9993 .999	3	1.000 .9997	3	.9990 .9987	3	.9984 .9987	3	.0004 .001	.0000 .0006	.0003 .0009
1 1/8	1.1235 1.123	5	1.125 – 1.1245	5	1.1230 – 1.1225	5	1.1220 – 1.1225	5	.0010 .002	.0000 .001	.0005 .0015
1 1/4	1.2485 1.248	5	1.250 – 1.2495	5	1.2480 – 1.2475	5	1.2470 – 1.2475	5	.0010 .002	.0000 .001	.0005 .0015
1 3/8	1.3735 1.373	5	1.375 – 1.3745	5	1.3730 – 1.3725	5	1.3720 – 1.3725	5	.0010 .002	.0000 .001	.0005 .0015
1 1/2	1.4985 1.498	5	1.500 – 1.4995	5	1.4980 – 1.4975	5	1.4970 – 1.4975	5	.0010 .002	.0000 .001	.0005 .0015
1 5/8	1.6235 1.623	5	1.625 – 1.6245	5	1.6230 – 1.6225	5	1.6220 – 1.6225	5	.0010 .002	.0000 .001	.0005 .0015
1 3/4	1.7485 1.748	5	1.750 – 1.7495	5	1.7480 – 1.7475	5	1.7470 – 1.7475	5	.0010 .002	.0000 .001	.0005 .0015
1 7/8	1.8735 1.873	5	1.875 – 1.8745	5	1.8730 – 1.8725	5	1.8720 – 1.8725	5	.0010 .002	.0000 .001	.0005 .0015
2 —	1.998 1.9975	5	2.000 – 1.9995	5	1.9975 – 1.9970	5	1.9960 – 1.9965	5	.0015 .0025	.0000 .001	.0010 .0020
2 1/8	2.123 2.1225	5	2.125 – 2.1245	5	2.1225 – 2.1220	5	2.1210 – 2.1215	5	.0015 .0025	.0000 .001	.0010 .0020
2 1/4	2.248 2.2475	5	2.250 – 2.2495	5	2.2475 – 2.2470	5	2.2460 – 2.2465	5	.0015 .0025	.0000 .001	.0010 .0020
2 3/8	2.373 2.3725	5	2.375 – 2.3745	5	2.3725 – 2.3720	5	2.3710 – 2.3715	5	.0015 .0025	.0000 .001	.0010 .0020
2 1/2	2.498 2.4975	5	2.500 – 2.4995	5	2.4975 – 2.4970	5	2.4960 – 2.4965	5	.0015 .0025	.0000 .001	.0010 .0020
2 3/4	2.748 2.7475	5	2.750 – 2.7495	5	2.7475 – 2.7470	5	2.7460 – 2.7465	5	.0015 .0025	.0000 .001	.0010 .0020
3 —	2.998 2.9975	5	3.000 – 2.9995	5	2.9975 – 2.9970	5	2.9960 – 2.9965	5	.0015 .0025	.0000 .001	.0010 .0020

TABLE 4 TOLERANCES AND SIZES FOR FITS



COMMERCIAL COLD DRAWN OR ROLLED BARS WHERE SHAFT DIAMETER IS UNIFORM TO STANDARD COMMERCIAL TOLERANCES AND FITS ARE OF LESSER IMPORTANCE THAN FOR GROUND SHAFTS

T=TOLERANCE GIVEN IN TENTHS OF THOUSANDTHS.

SIZE	SHAFT DIAMETERS MAX = BASIC	THOUSANDTHS TOLERANCE	HOLE SIZES FOR COMMERCIAL COLD DRAWN BARS. NOT USED ON STUDS OR GROUND SHAFTS. RUNNING FIT	T	WRING FIT	T	FORCE FIT	T	RESULTING FITS: RUNNING FIT INTERFERENCE	RUNNING FIT CLEARANCE	WRING FIT INTERFERENCE	FORCE FIT INTERFERENCE
1/4	.250 - .248	2	.250 - .2497	3	.248 - .2477	3	.2478 - .2475	3	.0003	.002	.0000 - .0023	.0002 - .0025
3/8	.375 - .372	3	.375 - .3747	3	.372 - .3717	3	.3718 - .3715	3	.0003	.003	.0000 - .0033	.0002 - .0035
1/2	.500 - .497	3	.500 - .4997	3	.497 - .4967	3	.4968 - .4965	3	.0003	.003	.0000 - .0033	.0002 - .0035
5/8	.625 - .622	3	.625 - .6247	3	.622 - .6217	3	.6218 - .6215	3	.0003	.003	.0000 - .0033	.0002 - .0035
3/4	.750 - .747	3	.750 - .7497	3	.747 - .7467	3	.7468 - .7465	3	.0003	.003	.0000 - .0033	.0002 - .0035
7/8	.875 - .872	3	.875 - .8747	3	.872 - .8717	3	.8718 - .8715	3	.0003	.003	.0000 - .0033	.0002 - .0035
1 —	1.000 - .997	3	1.000 - .9997	3	.997 - .9967	3	.9968 - .9965	3	.0003	.003	.0000 - .0033	.0002 - .0035
1-1/8	1.125 - 1.121	4	1.125 - 1.1245	5	1.121 - 1.1205	5	1.1205 - 1.120	5	.0005	.004	.0000 - .0045	.0005 - .005
1-1/4	1.250 - 1.246	4	1.250 - 1.2495	5	1.246 - 1.2455	5	1.2455 - 1.245	5	.0005	.004	.0000 - .0045	.0005 - .005
1-3/8	1.375 - 1.371	4	1.375 - 1.3745	5	1.371 - 1.3705	5	1.3705 - 1.370	5	.0005	.004	.0000 - .0045	.0005 - .005
1-1/2	1.500 - 1.496	4	1.500 - 1.4995	5	1.496 - 1.4955	5	1.4955 - 1.495	5	.0005	.004	.0000 - .0045	.0005 - .005
1-5/8	1.625 - 1.621	4	1.625 - 1.6245	5	1.621 - 1.6205	5	1.6215 - 1.621	5	.0005	.004	.0000 - .0045	.0005 - .005
1-3/4	1.750 - 1.746	4	1.750 - 1.7495	5	1.746 - 1.7455	5	1.7455 - 1.745	5	.0005	.004	.0000 - .0045	.0005 - .005
1-7/8	1.875 - 1.871	4	1.875 - 1.8745	5	1.871 - 1.8705	5	1.8705 - 1.870	5	.0005	.004	.0000 - .0045	.0005 - .005
2 —	2.000 - 1.996	4	2.000 - 1.9995	5	1.996 - 1.9955	5	1.995 - 1.9945	5	.0005	.004	.0000 - .0045	.001 - .0055
2-1/8	2.125 - 2.121	4	2.125 - 2.1245	5	2.121 - 2.1205	5	2.120 - 2.1195	5	.0005	.004	.0000 - .0045	.001 - .0055
2-1/4	2.250 - 2.246	4	2.250 - 2.2495	5	2.246 - 2.2455	5	2.245 - 2.2445	5	.0005	.004	.0000 - .0045	.001 - .0055
2-3/8	2.375 - 2.371	4	2.375 - 2.3745	5	2.371 - 2.3705	5	2.370 - 2.3695	5	.0005	.004	.0000 - .0045	.001 - .0055
2-1/2	2.500 - 2.496	4	2.500 - 2.4995	5	2.496 - 2.4955	5	2.495 - 2.4945	5	.0005	.004	.0000 - .0045	.001 - .0055
2-3/4	2.750 - 2.745	5	2.750 - 2.7495	5	2.745 - 2.7445	5	2.7435 - 2.743	5	.0005	.005	.0000 - .0055	.0015 - .007
3 —	3.000 - 2.995	5	3.000 - 2.9995	5	2.995 - 2.9945	5	2.9935 - 2.993	5	.0005	.005	.0000 - .0055	.0015 - .007

Commercial Cold-Drawn Bars

Table 4 shows sizes and tolerances for commercial cold-drawn or cold-rolled bars from $^1/_4$ to 3 in. diameter. The wide tolerances used by the steel mill will not permit this list to be used where close-fitting members are involved.

The tolerance of the steel mill is set arbitrarily from minus 0.002 in. on the $^1/_4$-in. size up to minus 0.003, 0.004, and 0.005 in. on the larger sizes.

In this tabulation the maximum of the hole for running fits is basic and *the shaft size is common* to all of the three kinds of fits.

Should the hole be to the low limit and the shaft to the high, an interference would be set up for a running fit, which is of course impractical, but it is just as likely that the maximum of the shaft is apt to be under basic.

When the shaft is oversize it is an easy matter to reduce its size slightly by a centerless grinding operation, in which case the tabulations for ground shafts would apply. It is common practice to purchase bars 0.005 to 0.007 in. over standard and centerless-grind them to size.

It will be noted, too, that the clearances for running fits and the interferences for both wring and force fits for this group run into figures that are not at all consistent with those established for the ground and turned parts, and it is anticipated that selective assembly or resizing must be resorted to when the limits under this classification run to the extremes.

Discussion

Luther D. Burlingame.[3] The author cites the Brown & Sharpe practice relative to medium fits, and states that he quotes from a paper by L. D. Burlingame, Trans. A.S.M.E., 1910. As the maximum clearance given by the author is materially more

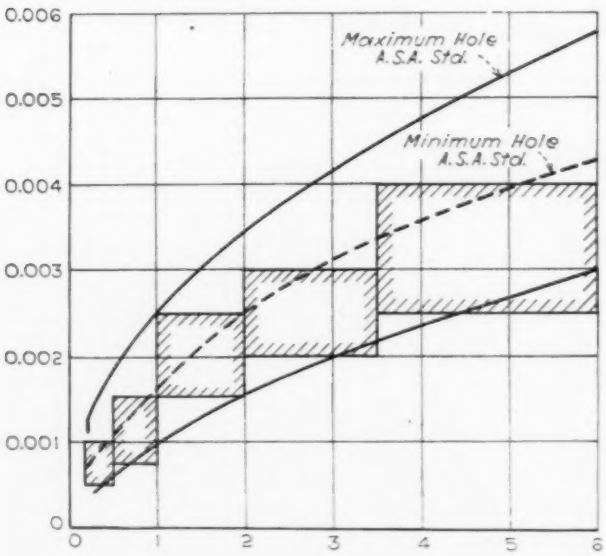


Fig. 16 Brown & Sharpe Present Practice

than is found in the paper presented by Mr. Burlingame at the joint meeting of the Institute of Mechanical Engineers and the A.S.M.E. in Birmingham, England, in 1910, and quoted in W. A. Viall's paper, "Precision Grinding," published in A.S.M.E. Trans., 1910, p. 1328, it is thought that the author has added the same limits for the holes which are used in his other calculations.

The Brown & Sharpe figures were based on standard hole practice and provide for materially closer running conditions than would be indicated by the author's diagram. Even these earlier figures of B. & S. practice have been superseded by closer

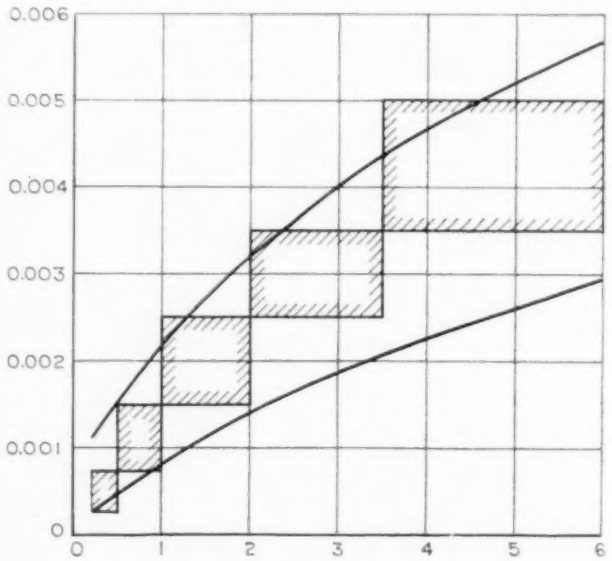


Fig. 17 Brown & Sharpe Early Practice

limits, as shown by the diagram, Fig. 16. These latter figures appear in the reference hand books such as "Machinery's Hand Book" of 1924, p. 980, and the "American Machinist Hand Book" of 1926, p. 540.

Even the earlier figures in the papers presented by Messrs. Viall and Burlingame in 1910, and charted in Fig. 17, follow closely the curves of the tentative American Standard, Class 3, Medium Fit.

That a reduction in the clearance allowed, from these earlier figures, has been possible, is due partly to improved methods of grinding and to improved methods of gaging. Modern grinding machines and processes make it possible to produce a better quality of surface, the advantageous results of which were clearly pointed out and emphasized in a paper, "A Survey of Surface Quality Standards," presented by R. E. W. Harrison at the December, 1930, meeting of the A.S.M.E. This paper clearly shows that by producing high-grade surfaces, which do not have to be worn into place, less clearance is required.

The American Standards Association Committee in its report dated January 2, 1923, presented formulas based on the B. & S. practice, which were adopted. The varying magnitudes of the successive steps of the B. & S. standard are in practically geometric progression, which is believed to be the correct grading.

The following figures represent the adopted B. & S. practice, and the diagram, Fig. 16 shows that they closely accord with the curves of the tentative American Standards, Class 3, Medium Fit:

To $^1/_2$ in. diameter, inclusive, 0.0005 to 0.001 small
To 1 in. diameter, inclusive, 0.00075 to 0.0015 small
To 2 in. diameter, inclusive, 0.0015 to 0.0025 small
To $3^1/_2$ in. diameter, inclusive, 0.0020 to 0.003 small
To 6 in. diameter, inclusive, 0.0025 to 0.004 small

Rowland MacDonald.[4] The question of establishing clearances is a difficult one. The author is to be congratulated on

[3] Legal Technician, Brown & Sharpe Mfg. Co., Providence, R. I., and Vice-Chairman of the A.S.A. Committee on Tolerances, Allowances, and Gages for Metal Fits. Mem. A.S.M.E.

[4] Small Motor Engineer, Westinghouse Elec. & Mfg. Co., East Springfield, Mass.

presenting a very useful paper, which will be of use to all engineers or others interested in bearing problems. The writer will confine his remarks to running fits on small-bore full-journal bearings.

At the Westinghouse plant at East Springfield, considerable experimenting in the laboratory has been done to determine suitable clearances and tolerances used on small motors. Where noise was a factor, it is true that close tolerances minimize vibration and resultant noise, but the lubrication problem then becomes a leading factor.

The replacement of reamed bearings for diamond-bored bearings has given very satisfactory results, and by using a diamond cutting tool, the clearances were reduced. Therefore, we have maximum wear and excellent surface finish. In line with this subject, a paper was presented by Mr. C. L. Bausch on diamond cutting tools at the Rochester meeting of the A.S.M.E. in May, 1929, which may be of interest.

The use of reamers at assembly to correct misalignment is an indication of failure in standardization. Clearance is dependent upon the materials used and ratio of L/D and the surface irregularities and lubrication.

Under controlling influences, the writer believes that two other factors should be considered, i.e., the nature of the finish on the journal and in the bearing, and the problem of lubrication using closer tolerances.

Under the nature of finish, the cutting tool should be considered. Since a reamer is a scraping tool in cutting, the chip breaks and the reamer undercuts and produces surface irregularities that elude measurement, but tend to break the oil film in the bearing. A reamed hole is seldom concentric. There is a tendency for the reamer to lift over the hard spots in the bearing and also toward making a bearing bell-mouthed. If there is an opening in the bearing for lubrication purposes, the reamer tends to cut an egg-shaped hole. The use of a diamond for cutting purposes does not have any of these disadvantages and produces a hard, smooth surface.

The clearances to be used seem dependent upon the method of lubrication, for example:

A waste-packed bearing requires close tolerances, good alignment, and polished surfaces due to partial lubrication.

A ring oil bearing usually will operate with less accurate alignment and greater tolerances due to fluid lubrication.

Close tolerances, very good alignment, and polished surfaces are necessary for pressure-feed lubrication due to the high pressures carried.

Care must be exercised in holding too close on clearances where green castings are used or warpage due to heat is possible. In the latter case, close tolerances would be extremely dangerous. In all cases, close tolerances affect the power required due to added friction. The writer believes that the lack of lubrication has been responsible for many bearing failures. A little consideration of the lubrication problem at the time of design will eliminate trouble due to this source.

In a comparison of clearance with other standards, the writer would make the following comments:

Fig. 1: The upper curve here tends toward a loose fit and removes potential wear. The writer would suggest that a maximum clearance of zero to $^1/_2$ in. diameter not to exceed 0.0010 in. and a maximum clearance $^1/_2$ in. to 1 in. in diameter not to exceed 0.0015 in. be used.

Fig. 2: In the first step, the nature of the surface would appear to be the controlling factor, as would alignment on most running fits. This tolerance seems to be too close.

Table 1: The Brown & Sharpe clearances are very close and require great accuracy and finish in their application, especially on diameters up to 1 in., in order to obtain satisfactory results.

The General Electric clearances do not seem logical and are out of proportion. The writer doubts if such clearances are specified on the small-bore bearings.

The American Machine & Foundry: The steps here seem well arranged and for ordinary reamed holes should be a satisfactory standard.

A.S.A.: The clearances here on the minimum scale are desirable while the maximum scale might be revised and brought in closer, so that there will be more potential wear on the bearing.

Fig. 3: In the experience of the writer, the tendency toward greater tightness under $1^1/_2$ in. diameter is sound and the leaning toward greater looseness above $1^3/_4$ in. is logical.

The practice of "running in" as a means of correcting an imperfect job does not seem reasonable. It is here that the minute surface irregularities wear off and one does not have a nice fitting job, and this is the beginning of trouble as these particles result in excessive wear, regardless of lubrication. The solution here would be surface finish.

Figs. 4 and 5: The running fits here are well arranged and within the desirable range. The writer could suggest only that there be three steps between zero and $1^1/_2$ instead of two as indicated in the graph.

The writer would like to ask the author to what extent the deflection of the journal will affect the film thickness of the lubricant in a bearing using standard practice running fits for the Kelly Press Division, and also his remarks on the effect of misalignment, nature of surface finish, and whether or not proper lubrication can be had with clearance established by the formula given in Fig. 5.

JOHN GAILLARD.[5] One of the merits of this interesting paper is that the author has given a clear picture of the character of the fits required by his industry. The needs of the Kelly Press Division appear to be covered by three classes of fits, called a "running," a "wring," and a "force" fit by this organization. The contents of the paper are the more interesting, as a reorganization meeting has just been held of a technical committee appointed under the auspices of the American Standards Association (A.S.A.) by the A.S.M.E. as the sponsor body, whose purpose it is to review and probably to revise and to supplement the present American standard on fits between cylindrical parts. This standard set up by the original committee, appointed in 1920, under the title "Tolerances, Allowances, and Gages for Metal Fits" (B4a-1925), was approved in 1925 by the A.S.A. as an American Tentative Standard. It has not been very widely introduced into practice, and it is believed that there are three main reasons for this lack of general adoption. First, it can safely be stated that the use of a system of limit gaging is still too rare. Besides a number of manufacturing concerns that have an effective and in some cases even a refined system of fits, there are numerous organizations that could adopt a standard system of fits with great benefits to their engineering, production, and inspection departments, but nevertheless still follow methods of trial and error in establishing fits as a function of the assembly work. Second, some organizations had a system of fits of their own when a national standard was established in 1925. As the maintenance of a system of fits requires a certain investment in tools and gages, this condition is apt to retard change to a new system. Also the replacement of parts of machines delivered and in operation is an important factor from the viewpoint of interchangeability. It is therefore reasonably to be expected that the adoption of a new system of fits will take some time under these circumstances. Third, criticism has been voiced against the American standard on the basis of the reamer situa-

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tion. Commercial stock reamers are commonly made with a small plus tolerance on nominal size. Consequently, they are not suitable for producing in an economical manner the basic to oversize holes required by the American standard. In fact, they soon wear down to the point where they begin to produce undersize holes and must then be rejected although they have still more wear left. Some systems of fits have therefore been proposed in which the holes are given minus tolerances on the nominal size, instead of plus tolerances, as specified in the American standard. In the opinion of the writer, it is not logical thus to adapt the system of holes to the existing tools, the more so if it is realized that the manufacturing limits of these tools were adopted before the present standard holes were established. On the contrary, the production tools—in this case reamers—should be adapted to the essential requirements of the standard fits, such as simplicity, flexibility, and facility in use by the designer, and maximum amount of interchangeability of parts. The possibility of this adaptability is no mere theory; it has been shown abroad that matters actually develop in this way. For example, in Germany, where a national standard system of fits has been generally adopted by all branches of industry (involving at least 1000 concerns), stock reamers have become adapted to the limits of standard holes and produce the latter economically by being used consecutively for different grades of holes, starting with the coarser and proceeding with the finer grades. Maximum wear life of the reamers is thus obtained.

Another criticism to which the American standard on fits has been subjected refers to the limited choice between fits of different character. The paper shows that still other fits than those specified in the standard may be needed by an industry—in this case, the printing-press manufacturers—whose requirements certainly are not too special to be disregarded by a national standard. Two fits are given as applied by the Kelly Press Division, one of which, the "running" fit, lies between the American Standard, Class 3 and Class 4, fits, while the other, the "force" fit, lies between the American Standard, Class 7 and Class 8, fits. In revising the existing American standard, the new committee should therefore consider an increase in the number of standard shafts and in the number of allowances so as to give the system as a whole greater flexibility in the hands of the designer.

Another deficiency of the present standard which has been brought to the attention of the A.S.A. before, is the lack of a series of fits in the basic shaft system; that is a series of fits in which the maximum size of the shaft is kept constant, the hole being varied to get the desired fit. The need for such fits is also felt by the Kelly Press Division, according to the author. A concern which by the nature of its product can use exclusively, or to a large extent, bar stock, supplied in cold-finished or centerless-ground condition, without giving such stock a machine finish, can in principle make good use of a basic shaft system.

The unification of standard fits, nationally (and also internationally) is a matter of primary importance to the mechanical and other industries. If individual organizations, however important they may be, adopt their own system of fits, all of these systems differing from each other, industry as a whole will not get the maximum benefit that may be derived from unity in tools and gages and in manufacturing practice. Only real cooperation resulting in a nation-wide compromise can establish a unified system, and complete success furthermore requires adoption of the national standard, both by organizations that have not yet used a standard system of fits and by those who have to make some change from their existing system.

It is quite interesting to note, for example, how at present the several fits of the Kelly Press Division actually belong to three sub-systems used according to whether ground studs or other internal parts, ground shafts with uniform diameter throughout their length, or cold-drawn (and not ground) shafts are used. The diversity has evidently grown up in the course of time on the basis of workshop practice not yet coordinated by a unified system. A graphical analysis of the nine fits involved will show that they might be replaced by three, either in the basic hole or the basic shaft system. Such replacement would result in a considerable simplification in tools and gages and in design and manufacturing practice, and although the changes involved may cause some difficulty, or may to some extent even be impracticable with regard to product already sold and in operation, consideration might well be given to such a scheme for new product.

It is very gratifying to know that Mr. Reiman, who has given the subject such thorough consideration, has been appointed a member of the reorganized A.S.A. technical committee on "Fits between cylindrical parts and limit gages," as the representative of the Printing Press Manufacturers' Association. Only such cooperation of the different industries, based on expert knowledge of their particular needs, combined with willingness to view the national problem as a whole, can result in a standard serving the needs of all.

In concluding, it may be said that also the international unification of standard fits has been given a great deal of attention. There are now altogether twelve countries, including the United States, where a national system has been adopted, and when some years ago an International Standards Association (I.S.A.) was founded, of which the A.S.A. is a member, the question naturally arose whether international agreement could be reached. A proposal for a unified system is now being developed under the auspices of the I.S.A., and the new A.S.A. committee has just declared its willingness to cooperate in this effort.

PI-52-11

Forces in Connection With the Reciprocating Beds of Flat-Bed Cylinder Printing Presses

By B. D. STEVENS[1] and H. E. GOLBER,[2] CHICAGO, ILL.

This article deals with printing-press beds, their mechanisms, and forces. The mechanisms of some well-known presses are described sufficiently to show that the dynamic problems are identical for all. The forces are examined as to their effect upon the motor, the machine, and the building. Reference is made to certain methods which have been tried for reducing or counterbalancing them, and some criticisms and suggestions are made.

THE purpose of this paper is to arouse interest in the forces exerted and the mechanism used to reciprocate the beds of flat-bed printing presses. The scope is an analysis of the bed motions used on presses on the American market.



B. D. Stevens

These bed motions have either (1) a simple, roughly harmonic motion or (2) a compound motion, treated more fully below. Among the first class are the Miehle Vertical, the Autopress, the Miller High Speed, etc. These presses have their beds reciprocated by means of cranks and connecting rods or their equivalent. The motion of the bed is thus roughly harmonic. As the problems that arise with these presses of the first class also arise with the presses of the second class, the discussion will go directly to the latter, to which belong all the Miehles (except the Vertical), the Babcocks, the Whitlock-Premiers, the Kellys, the Miller Simplex, etc.

A typical compound motion of a flat bed may be visualized thus: Imagine (Fig. 1) a circuit *ABCDEF*, where *BC* and *EF* are straight-line segments and the curves *CDE* and *FAB* are semicircles. Imagine a point *P* traveling around the circuits at constant speed. Let *M* be a projection of *P* on the line *AD*, so that *M* and *P* always have the same velocity horizontally. As *P* travels around the circuit, *M* will reciprocate along *AD*.

Now consider the point *M* to be a part of a flat bed, being fastened thereto in some manner. The motion of the bed is thus the motion of *M*, and the bed movement is easily followed.

It thus is seen that, for the period *BC*, the bed travels at uniform velocity from *Q* to *O*. For the period *CDE*, *P* travels in a semicircle, and therefore *M* and the bed slow down and speed up harmonically from *O* to *D* and back to *O*. For the period *EF*, the motion is uniform, and for the period *FAB*, it is again harmonic.



H. E. Golber

While the relation between the length of the segment *BC* and the length of the arc *CDE* may be varied, some of the presses aforementioned, for instance, the Miehles and the Babcocks, make the length of *CDE* equal to one-half the length of *BC*. The Miller Simplex, however, makes the length *CDE* equal to *BC*. This immediately determines the timing of the forces occurring, for instance in the Miehle:

Period *AB* = 1/12 of cycle = harmonic acceleration
Period *BC* = 1/6 of cycle = no force
Period *CD* = 1/12 of cycle = harmonic deceleration
Period *DE* = 1/12 of cycle = harmonic acceleration in reverse direction
Period *EF* = 1/6 of cycle = no force
Period *FA* = 1/12 of cycle = harmonic deceleration.

Attention is called to the fact that, although during the periods *CD* and *DE* the bed moves first to the left and then to the right, thus reversing its direction, nevertheless the force acts always in the same direction, namely, to the right; similarly for the periods *FA* and *AB*, the force acts to the left.

Above, for the period *BC*, is stated "no force." Frictional forces of course do occur during this period, but in this paper frictional forces are not taken into account.

When it comes to the actual kinematics for producing the motion of *M*, it is found that the various presses have different mechanisms.

For the uniform motion parts, namely, *BC* and *EF*, some presses (some Miehles) have (see Fig. 2) a driving gear *G*, always rotating in the same direction, and meshing first with an upper rack R_1, and second with a lower rack R_2, both racks being fastened to the bed. The two racks face toward each other, and are apart approximately the diameter of the gear. The gear meshes with one rack at a time, and is moved slightly axially or vertically to unmesh from one rack and to mesh with the other.

In other presses, for instance, the Babcock, the construction is inverted. Here the two racks R_1 and R_2 are placed in the center while the gear *G* is moved from above the racks to below the racks to engage first with one rack and then with the other rack.

In still other presses reversing gears are used. The variations are numerous, and will not be further entered upon.

When it comes to the mechanism for accomplishing the harmonic part of the movement *CD* during the periods *CDE* or *FAB*

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Contributed by the Printing Industries Division and presented at the Annual Meeting, New York, N. Y., Dec. 1 to 5, 1930, of The American Society of Mechanical Engineers, 29 West 39th Street, New York, N. Y.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

(Fig. 1), there again is found a great variety. Generally the mechanism is a special means which is not connected to the bed during the periods BC and EF, but does become connected at, say, C, remains connected during the period CDE, and becomes disconnected at E. The particular kind of mechanism varies, and some will be indicated below.

There are some presses whose harmonic mechanism consists of a harmonically reciprocating gear, making three reciprocations

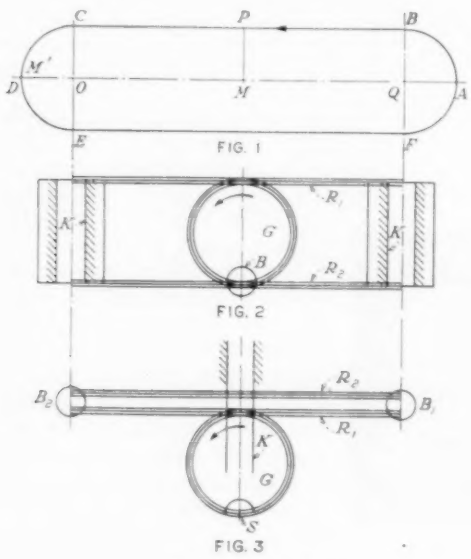


FIG. 1

FIG. 2

FIG. 3

FIGS. 1, 2, AND 3

per impression. Among them are the Kelly and the Miehle Horizontal. The reciprocating gear is given its harmonic reciprocation by a crank and a connecting rod or its equivalent. The reciprocating gear meshes with the bed at, say, C, and during the period CDE imparts its motion to the bed, until at point E the bed becomes unmeshed, ordinarily because it runs off beyond the range of the gear.

The Babcock press has a mechanism that at first view seems radically different, but on analysis is found to be a kinematic equivalent. Referring to Fig. 3, it will be seen that at each end of the double rack there is a roller ball B_1 and B_2. Cooperating with the roller is a socket S on the gear G. As the gear rotates, and drives the rack and bed, the socket S comes nearer and finally embraces the roller B_1. At that moment (see C, Fig. 1), the gear runs out of the rack, but the socket connects with the roller ball and drives the same. The motion is such that the gear center always keeps at a constant distance from the roller center, and the gear center moves straight up and down in a groove K. Upon analysis this is found to give the roller a harmonic motion, and thus the bed itself receives a harmonic motion.

The Miehle press has a mechanically different construction, but one which is again a kinematic equivalent. Referring to Fig. 2, there is a roller B, but here it is attached to the gear shaft and thus operates as a crank. The roller has a circular motion, which may be decomposed into a vertical component and into a horizontal one. The roller B rolls in vertical grooves K, which are attached to the bed. The bed is thus given a harmonic motion while the crank moves through a semicircle bounded by a vertical diameter.

Other variations are introduced in other presses. For instance, the Miller Simplex, departing from the vertical groove K and vertical diameter, employs a groove oblique at 45 deg. The bed still moves horizontally.

To make the mechanism operate, the operating diameter of the crank semicircle is changed from vertical to oblique. While the roller moves in the direction of the arrow, from the position B_1 to B_2, the inclined slot moves from the diametral to the tangential position. While the roller moves from B_2 through B_3 to B_4, the inclined slot moves back to the diametral position. On account of the inclination, the lower portion of the inclined slot is run over twice, once for the travel B_2 to B_3 and again for the travel B_3 to B_4. But the motion of the slot measured perpendicularly to the diameter B_1B_4 is obviously harmonic, and since every parallel-line projection of a harmonic motion is also a harmonic motion, the horizontal movement of the bed of the Miller Simplex is a harmonic motion.

So it is seen that the forces of the flat beds of cylinder presses, whether Whitlock-Premiers, Babcocks, Miehles, or Millers, are those arising from uniform travel and harmonic acceleration. They are all in the same class and may thus be treated together.

It is well known that in all machinery, going through any motion, the forces that occur are a function of both the mass of the moving parts and the speed of the machines. The forces vary directly as the mass and directly as the square of the speed. Also it is known that in harmonic motion the force varies directly as the distance from the center (see O, Fig. 1). So, given the weight of the bed W, the speed or number of impressions per hour, and the length of the radius OD (Fig. 1), the forces can be completely calculated.

The forces, as outlined in the foregoing, while of interest as an academic problem only, manifest themselves pragmatically as well. These forces manifest themselves in three different aspects:

(1) The effect on the motor
(2) The effect on the structure of the machine
(3) The effect on the building.

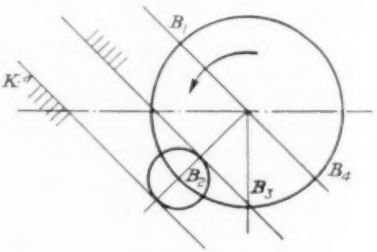


FIG. 4

These will be treated in order.

The effect on the motor is not very important. The flywheel is a storehouse of energy and carries enough to smooth out the inequalities due to the reversal of the bed sufficiently for commercial purposes. Should speeds be increased or other conditions make it desirable, perhaps something like the kinetic energy reservoir (U. S. patent 1,126,750) might be considered.

The effect on the structure of the machine is very noticeable. The reversing roller B must endure the forces necessary to reverse the bed. These are quite considerable. For instance, in a Miehle No. 4 press, the bed and moving associated parts weigh approximately 1500 lb. At a speed of 3300 impressions per hour, the maximum force on the roller would be about 7000 lb. This pressure is great enough to warrant means for counteracting it, and these means have been of various kinds.

Many attempted to reduce the weight of the bed. Thus, instead of cast iron, welded steel has been used. Aluminum and its alloys have been considered. Now that beryllium is suggested for commercial use, with great strength and lightness, it also might be considered. Thus far, however, cast iron is the standard.

Others have reduced the length of the stroke. However, as the motion of the bed relative to the impression cylinder depends on the length of the maximum sheet, that relative stroke must be preserved. What was taken off the stroke of the bed was there-

fore added to the cylinder. Nevertheless, by this means something might be gained, as the total kinetic energy of both bed and cylinder might be decreased. This has been done in the Autopress, the Miller High Speed, and the Miehle Vertical, where the bed and cylinders each move one-half the distance in opposite directions.

Attempts have been made along other lines. Some time ago spring bumpers were tried to help in stopping the bed at the end of its stroke. These springs theoretically operate according to Hooke's law that the force is directly proportional to the distance the spring is compressed. As the force of a harmonic movement is also directly proportional to the distance OM^1 (see Fig. 1), the spring could be made to theoretically balance the bed force. However, the difficulties encountered in making the spring bumper shockless, and to adapt it to various speeds and to prevent the springs from breaking under the rather large forces, kept that solution from coming into general use.

Instead of metal springs, air springs were proposed. Air buffers are quite generally used, and any one who wishes to convince himself of their value may easily do so by comparing the operation of a press with the air spring functioning and again not functioning.

The air spring is generally composed of a cylinder and a piston for compressing the air during the stopping of the bed. This compressed air helps to start the bed in the opposite direction. There are certain laws in connection with air springs that will

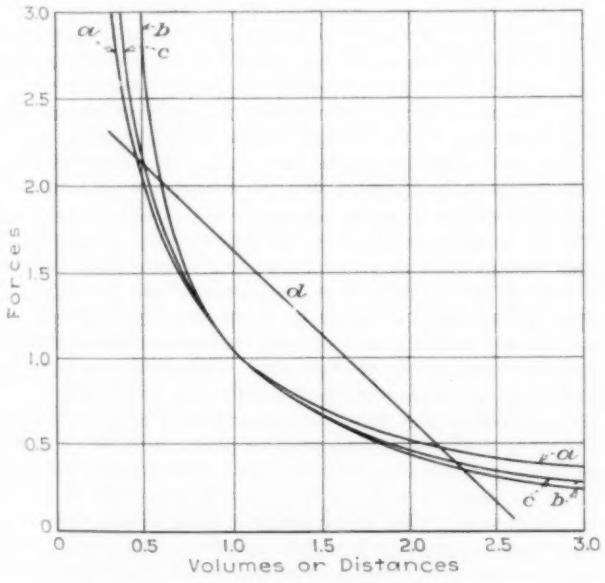


FIG. 5

now be considered. The law of compressing air isothermically is Boyle's Law $PV = C$, or pressure $\times$ volume = constant. In the rapid operation of a modern flat-bed printing press, the air might be considered to be compressed adiabatically with the law $PV^{1.41} = C$. However, in practice a modified law is found better and is assumed to be $PV^{1.3} = C$.

It has been stated in the foregoing that the change of volume occurs by the motion of a piston in a cylinder. The volume may therefore be considered a cylindrical volume, and thus proportional to the length of the cylinder. The law might therefore be changed to $PL^{1.3} = C$, where L is the length of the column of compressed air in the cylinder.

If we lay out a graph, Fig. 5, making the ordinates represent the forces and the abscissas represent the lengths, we find that Boyle's Law $PV = C$ gives a rectangular hyperbola a. The adiabatic curve $PV^{1.4} = C$ is shown as b, while the accepted curve $PV^{1.3} = C$ is shown as c between the other two curves. The three curves cross each other at the point $P = 1$ $V = 1$. They are all hyperbolas of various kinds, and their properties are described in many books, for instance, Steinmetz's "Engineering Mathematics."

If we make a similar graph for the harmonic forces of the flat bed, we find the curve to be an inclined straight line d. The problem of balancing the bed forces by the air spring thus reduces to the superposing of the straight line d upon the hyperbola c. It is manifest that this is impossible. The straight line at best can be made to intersect the hyperbola in only two points, and the best that can be done is to make the differential ordinates (or forces) as small as possible.

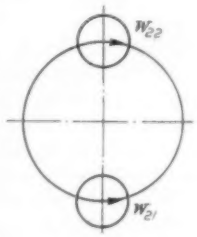


FIG. 6

Moreover, another consideration must be taken into account. The bed forces vary as the square of the speed of the machine. The tangent of the angle of d or its slope therefore varies as the square of the speed of the press. But the formula for air compression $PL^{1.3} = C$ is not varied with the speed. A best match for one speed therefore becomes a poor match for another speed, and it very readily happens that a poor match will introduce differential forces larger than the ones attempted to be matched. It is therefore desirable to introduce mechanism for changing the adaptation of the air spring to the bed forces depending on the speed of the press.

On the larger Miehle presses, this has been done in two ways. Recalling that the Miehle air spring consists of a moving piston trapping air in a stationary cylinder. it is easily seen that one variation might be introduced by the piston trapping the air earlier or later. This is accomplished in practice by keeping a valve open to allow the trapped air to escape until the desired time when the valve is shut—earlier for high speed, later for low speed. This is done by means of a centrifugal governor and cooperating mechanism.

Another method is by enlarging or diminishing the dead volume at the end of the compression stroke.

The foregoing very general treatment of the air spring shows how far-reaching a discussion of it may become, so we will halt here and return to the general problem.

Referring again to Fig. 1, it was stated that in most presses the arcs CDE and FAB were semicircles. The semicircle has been adopted, however, for machining reasons, not for dynamic reasons. Its harmonic motion can be produced on standard machine tools, whereas other motions cannot be so readily produced.

A good deal of thought has been given to the foregoing question, and it was noticed that a parabolic curve no doubt has some advantages. It is the curve of a body falling under gravity, and gravity operates without shock. Upon making the comparison, it is found that the parabolic curve produces a constant force like gravity, while the semicircle produces a varying force, directly proportional to the distance from O, and therefore having a maximum at D. Moreover, calculation shows that

$$\frac{\text{Constant Parabolic Force}}{\text{Maximum Harmonic Force}} = \frac{2}{\pi}$$

or roughly $^2/_3$. Since the force increases as the square of the speed of the press, it is seen that a press with parabolic mechanism could be run $\sqrt{\pi/2} = 1.25$ times as fast as the press with the harmonic mechanism before the constant force of the first press would equal the maximum force of the second press.

There will now be taken up the effect of the bed forces on the building. They manifest themselves, particularly with big presses and weak buildings, by shaking the building, so much so that in some cases the operation of the press has to be stopped.

It has been pointed out previously that the heavy bed runs at a uniform velocity during the period (*BC*, Fig. 1), and is stopped and reversed during the period *CDE*. The kinetic energy of the bed must therefore be somehow absorbed. Generally it is absorbed by the building. True, there has been a discussion of air springs, etc. to balance the forces of the bed, and the air spring is somewhat successful in doing so. But when the bed force goes into the compressed air in the cylinder, the air pushes on the bottom of the cylinder, which pushes on the frame, and which in turn pushes on the building to an amount just the same as if the air springs were not there at all. The effect on the building remains totally unchanged.

Several suggestions have been made, and some of them are in use. Thus since buildings are generally built to withstand vertical stresses better than horizontal ones, the bed motion has been made vertical in some presses. But this is practical in small presses only, where but little trouble would be encountered.

It has been suggested that the press be allowed to move somewhat on the floor, and allow the heavy press base to absorb the kinetic energy of the bed. This suggestion has been tried out, but has not found favor.

Another suggestion is that the bed energy be balanced internally in the machine by making the framing very much heavier. This may help, but has objections of its own.

Still another suggestion is to balance the bed forces internally in the machine. Many years ago a patent was issued showing a balancing weight moving in the direction opposite to the bed. This method would balance the effect on the building, but would double the forces on the crankpin, air spring, etc.

Some variants of the preceding were made. Thus, as mentioned before, in the Miehle Vertical the bed and cylinder move in opposite directions, thus balancing each other and eliminating the effect on the building.

The question has been asked, Could not the bed motion be completely balanced by bodies rotating at uniform velocity about fixed axes? Upon further consideration, this was seen to be equivalent to the decomposition of the bed motion of Fig. 1 into a Fourier series.

This has been accomplished, and it was found that the bed motion forces can be completely balanced by a set of eccentric weights W_1, W_3, W_5, located at crank radii of respectively r_1, r_3, r_5, and having the following values:

$W_1r_1 = 3.72\ WR$ one revolution per impression
$W_3r_3 = 0.333\ WR$ three revolutions per impression
$W_5r_5 = 0.074\ WR$ five revolutions per impression
$W_7r_7 = 0.015\ WR$ seven revolutions per impression, etc.

where W is the weight of the bed and $R = OD$ (Fig. 1).

Of course, these rotating balancing weights were calculated to completely balance the horizontal bed forces on the building, but might themselves introduce unbalanced vertical forces. These vertical forces, however, may be completely balanced by replacing each one of the foregoing rotating weights, say W_3, by a couple of rotating weights W_{21} and W_{22} (Fig. 6), the two weights in each couple rotating at the same speed in opposite directions, and so arranged as to have one weight move up while the other moves down, and while both weights move horizontally together (Fig. 6).

The problem can thus be considered to be dynamically solved, but when it comes to reducing it to practice, the question of distribution of the weights and the mechanism to drive them is a problem in itself.

Discussion

W. S. Huson.[3] This paper, which contributes in a technical manner to the problems of forces at work in the reversal of reciprocating bodies, as in printing presses, brings out some factors that seem to be hard for the average mind to grasp—first, that the work of stopping and starting a body is hardest on the driving mechanism and not keeping the moving body in motion; second, that the positive space in which retardation and acceleration must take place compels positive control that proper synchronism be maintained with other parts of the machine. In a steam engine the reciprocating piston is cushioned at the ends of the stroke by the compression and expansion of a residuum of steam in the cylinder and by the absorption of some of the work by the crank and heavy flywheel. In designing a press, however, where in the main there is no opportunity for a heavy foundation and provisions to suitably adapt the reciprocating parts to theoretical requirements, the endeavor is to find a solution that will give in the best possible way a practical cushioning device that will better absorb the momentum, relieve the strain on the driving mechanism, and which, in the endeavor to counteract the overwork on it, transmits it to the press as a whole; hence the tendency to move on the floor, and the need for better control is accentuated by the increased speed at which presses are run.

That the need for something to stop and start the bed was early recognized is shown by the variety of adaptations of coil springs—in some foreign presses by leaf springs—the endeavor being to meet the oncoming body by an absorbing element that was adjusted to meet the load by presenting a reacting load in which one would dissipate the other. The ability to preset a nest of springs to an initial load was the dominant feature, and while the coil springs have been abandoned, they had that feature which the later air springs do not have, for in the air spring the initial pressure must be built up to several atmospheres before it becomes effective and that done at each stroke of the reciprocating bed. That presses could be made heavier or moving parts lighter seems to be beside the question. The problem is to adequately overcome the impetus imparted to the moving body and return it to its previous state, and this without shock or undue stress on the parts. To this end the paper is a helpful one in the manner in which it sets forth the complex nature of the problem and portrays a deep study of it.

[3] Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

Progress in Railroad Mechanical Engineering

Contributed by the Railroad Division

Executive Committee: R. S. McConnell, *Chairman*, M. B. Richardson, *Secretary*, A. F. Stuebing, Eliot Sumner, A. G. Trumbull, and J. B. Ennis

FUNDAMENTAL conditions in the railroad field show little change since last year. Developments in operation and traffic are still following the general trends and tendencies noted in the preceding report of this division. However, the present situation discloses some distinct changes from that of a year ago. The volume of freight traffic in 1929 has been greater than in any previous year; the average weekly car loadings for the first nine months have been 1,051,000, or 7.5 per cent greater than in 1928. While new records for operating efficiency have been established and the ton-miles per freight car have been increased, the surplus of freight cars has declined from the high level of 1928. This apparently has been responsible for renewed activity in the purchase of equipment. For the first nine months the number of freight cars ordered totaled 66,190. Although this number is small compared with record years, it is 169 per cent greater than purchases in the corresponding period of 1928. Locomotives ordered up to October 1 totaled 672, or 170 per cent more than for the first nine months of the preceding year. The tonnage of rails purchased has been large and the major proportion has been of heavy section, indicative of the railroads' purpose to improve their properties and reduce maintenance costs by investments in the most modern facilities.

The continued growth of passenger travel by highway buses has led the railroads to enter this field more extensively and to coordinate train and bus service. The schedules of through trains on trunk-line and western routes have been reduced and more fast trains have been put in service, especially between New York and Chicago. Advocates of the use of inland waterways for freight transportation have been very active, but their arguments have been offset by the reports of independent analysts who have shown that in practically every case the apparent savings in freight rates are more than offset by the fixed charges on the cost of making the routes navigable and providing necessary facilities. A survey of technical developments reveals many innovations in equipment. The variety of designs and types of locomotives is particularly noteworthy.

High-Pressure Locomotives

The interest in locomotives operating at high pressures and the extent to which this means of increasing thermal efficiency is gaining acceptance are evidenced by the numerous designs now being tried. Double-pressure locomotives of the type originated by the Schmidtsche Heissdampf Gesellschaft and described in the paper by R. P. Wagner presented at the 1928 meeting of the Society, have been placed in service on the London Midland and Scottish and the Paris-Lyons-Mediterranean. Similar designs are now being prepared for the New York Central and the Canadian Pacific.

Another high-pressure locomotive built recently in Germany is the Schwartzkopff-Loeffler type, utilizing steam at pressures of approximately 1500 lb. per sq. in., which will be tested on the German State Railways.

The Swiss Locomotive and Machine Works of Winterthur has built a passenger locomotive of novel design with a geared uniflow engine connected to the driving wheels through a geared jackshaft. The boiler pressure is 850 lb. per sq. in. In comparative trials with a locomotive of standard type this design showed a coal saving of 35 per cent.

H. N. Gresley of the London and North Eastern has prepared a design for a high-pressure locomotive to be fitted with a Yarrow-type boiler.

After several years' experience with two locomotives operating at pressures of 350 and 400 lb., the Delaware & Hudson has placed an order for a third which will carry 500 lb. boiler pressure. The engine will be of the cross-compound type.

Turbine Locomotives

Various arrangements for adapting steam turbines to locomotive service are being tried, of which perhaps the most significant is the use of the non-condensing turbine. The Oxelosund-Flen-Westmanlands Railways have ordered two locomotives with back-pressure turbines designed by the Ljungström Steam Turbine Company, which will be built by Nydquist & Holm. The advantages expected are 25 per cent greater starting tractive force than with the reciprocating engine and 20 per cent fuel saving, with a probable reduction in maintenance expenses. The Ljungström Company further proposes the conversion of piston locomotives to non-condensing turbine locomotives by replacing the cylinders with a back-pressure turbine driving through reduction gears and a jackshaft.

Internal-Combustion Locomotives

During the past year the Canadian National Railways placed in service the most powerful oil-electric locomotive ever built. This is especially noteworthy because it is the first of the internal-combustion type which approaches the power output of the modern steam locomotive. Two units make up the complete locomotive, which weighs 650,000 lb., with 480,000 lb. on the driving wheels. The wheel arrangement is of the 4-8-2-2-8-4 type. Motive power is provided by two 12-cylinder Beardmore high-speed solid-injection oil engines of 12 in. bore and 12 in. stroke, rated at 1330 hp. at 800 r.p.m. The fuel consumption of the engines is 0.43 lb. per hp-hr.

A comparison of this locomotive with the latest steam locomotives for passenger service on the same road shows that from 20 m.p.h. to maximum speed the steam locomotive develops slightly greater tractive force, but below 20 m.p.h. the advantage is in favor of the oil-electric which develops a tractive force up to 100,000 lb., whereas the maximum for the steam locomotive is 49,600 lb. Designs have been prepared for a similar locomotive for freight service, which will develop a maximum tractive force of 130,000 lb.

The Baldwin Locomotive Works has recently built an oil-electric locomotive designed for switching service and equipped with a 1000-hp. Krupp Diesel engine. This locomotive, which has a total weight of 270,000 lb., is carried on four pairs of drivers in two articulated four-wheel trucks. The engine is of the four-cycle airless-injection type with six cylinders of 15 in. bore and 15 in. stroke, operating at 250 to 500 r.p.m. A compressor attached to the engine furnishes air for the brakes, for starting, and also for supercharging the engine at about 6 lb. per sq. in. pressure. The generator and four motors operate at 550 volts d.c. The

theoretical tractive force is 67,500 lb. up to 5 m.p.h. The control equipment is arranged so that the locomotive can be operated from either end. A noteworthy innovation is the arrangement for varying the speed of the oil engine as required, which consists of a connection by levers and hydraulic cylinders from the electric controller to a cam on the governor which manipulates the throttle of the engine.

Another noteworthy design is the 900-hp. Diesel-electric passenger locomotive built by the American Locomotive Company for the New York Central. This has four-wheel trucks at each end and eight driving wheels in the main frame. The engine is a 12-cylinder "V" type built by McIntosh & Seymour. The cylinders are 14 in. in diameter by 18 in. stroke, and develop 900 b.hp. at 310 r.p.m., with 10 per cent overload capacity. Air injection is used and fuel pumps are governed by electric regulation which controls the amount of oil supplied to the cylinders and the torque developed. The main generator has 10 main poles and 10 commutating poles, and is connected directly to the engine.

The Krupp Works have built a Diesel locomotive with a mechanical-magnetic transmission for the Boston & Maine, which has not yet been delivered. The total weight is 314,000 lb. and the maximum tractive force 50,000 lb.

The first application of the Still combined internal-combustion and steam engine to railway traction has been embodied in a locomotive built by Kitson & Co., Leeds. The motive power consists of a four-stroke heavy-oil engine of the horizontal opposed type with eight cylinders. The cylinders and crankshaft are in a plane slightly above the top of the locomotive frames. The engine is geared to a jackshaft which drives the wheels through connecting and coupling rods. The water jackets of the internal-combustion cylinders are coupled by pipes to a boiler located above the engine. This boiler supplies steam which can be applied to the inner sides of the pistons for starting or to furnish auxiliary power on steep grades. The boiler carries a pressure of 200 lb. per sq. in. and is fired when needed by an oil burner. Heat is also applied from the exhaust gases of the oil engine.

The locomotive is of the 2-6-2 type with 60-in. drivers and weighs 195,000 lb. The engine is of 13½ in. bore and 15½ in stroke, designed for a maximum speed of 420 r.p.m., corresponding to a locomotive speed of 40 m.p.h. The fuel is injected without air. On trial runs the engine has commenced to fire at 3 m.p.h. and has operated at speeds up to 45 m.p.h. The tractive force developed was 25,000 lb. with steam alone and 7000 lb. at 45 m.p.h. with internal combustion only. Test runs have been made on the London and North Eastern Railway with both freight and passenger trains. The incomplete data now available indicate that the oil-engine consumption was approximately 10 lb. per 1000 gross ton-miles. It is anticipated that the fuel consumption of the boiler will under average conditions approximately equal the engine consumption. While these figures are far below the best records for steam locomotives in similar service, it is thought that the Still locomotive will give its best results on longer runs with fewer stops and less severe grades.

The most noteworthy locomotive of what may be considered the standard type built during the past year was the single-expansion articulated 2-8-8-4 design for the Northern Pacific, the largest and most powerful steam locomotive in the world. The total weight of engine and tender is 1,116,000 lb., of which 715,000 lb. is the weight of the engine alone. The tractive force of the main engines at 70 per cent cut-off is 139,900 lb., and with 13,400 lb. additional tractive force developed by the booster, the combined tractive force is 153,300 lb.

The Northern Pacific locomotive is especially designed to burn eastern Montana sub-bituminous coal which is high in moisture and has relatively low heating value, necessitating the use of a boiler with 182 sq. ft. of grate area to develop the power required. That the problems involved in the design were successfully met is indicated by the fact that the railroad has placed a second order for locomotives of the same type.

Another interesting development in special fuel is the application of pulverized fuel in Germany. Two different designs are being tried. One has burners extending along both sides of the firebox with multiple slots and water-cooled chambers, the jets impinging against one another in the middle of the firebox. The other type has a diffuser burner in the form of a hollow cone, the enlarged front end of which is closed by a plate having numerous nozzle-shaped holes. The small rear end adjoins a mixing device for the coal dust and air mixture. The diffuser plates are flush with the back plate of the firebox, while the burner bodies are outside. The diffuser plate, which is the only part exposed to radiant heat, is cooled by the coal dust and air mixture.

Freight Cars

The most significant development during the year pertaining to car equipment was the report of the draft-gear tests conducted by the Mechanical Division of the American Railway Association. Following extensive laboratory investigations of draft gears now in general use, the committee submitted tentative specifications setting forth requirements for capacity, sturdiness, endurance, and recoil. The work of the committee will be carried still further, and it is expected that important improvements in draft gears will result from their investigation.

Further extension of the use of special refrigerating systems mentioned in previous reports is indicated by the announcement that the company developing the silica-gel system of refrigeration has placed an order for 50 additional refrigerator cars to be so equipped.

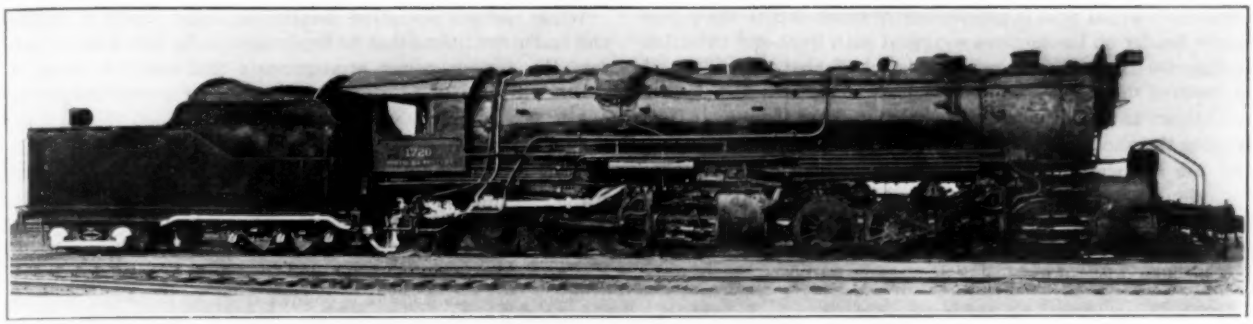


FIG. 1 SINGLE UNIT AUXLOCO APPLICATION TO MALLET HELPER LOCOMOTIVE

Locomotive Auxiliary Power Mediums

BY GEORGE W. ARMSTRONG,[1] BETHLEHEM, PA.

In this paper the author describes the Bethlehem auxiliary locomotive and gives some test results. A self-contained power truck is provided which can replace one of the regular tender trucks, either a front or rear truck of the locomotive, and in some cases to replace both trucks. Ordinarily the rear-truck installation is recommended as it facilitates removal for inspection and maintenance.

EARLY in the development of the steam locomotive efforts were directed toward auxiliary power which would enable the locomotive to handle a more equalized load on gradients and level track without the use of assistant or helper locomotives. The Sturrock locomotive, which consisted of a supplemental locomotive under the tender, is the earliest known application. Some 65 of these locomotives were in use on English railways in 1865. The locomotive under the tender was used only at slow speeds on grades.

The limitations of the small engines of that day in steaming capacity, the excessive steam demand due to condensation with the use of saturated steam, together with the maintenance requirements of a unit always in use, whether operated or not, all combined to sound the death knell for these early attempts.

It is only within recent years, with the extensive use of superheated steam, the development of large power units, and the application of the automatic stoker, eliminating the limitations of firing capacity, that the practical application of auxiliary power for locomotives has been realized.

The concept of railroading, in the meantime, has changed in conformity with the present-day economic necessity, so that this applied auxiliary power is utilized not only as originally considered as a compromise assistant or helper locomotive, but as a starting medium.

Service, the only commodity which the railroad has to sell, demands rapid transportation. Freight trains today are being run at speeds comparable with passenger schedules of not so many years ago. This has brought into existence a locomotive with large driving wheels, 69-in. and 73-in. wheels being common for many recent freight locomotives, as contrasted with 57-in. and 63-in. wheels of 10 or 15 years back.

Along with this trend is the desire to secure the maximum tractive effort permitted by the allowable weight on drivers, which has resulted in a gradual lowering of the factor of adhesion, or ratio of driving-wheel weight to cylinder tractive power. The combination of these two factors has resulted in a locomotive with high sustained power at speed, due to the boiler capacity combined with the lowered piston speeds, and at the same time, an engine of greater tendency toward slipping.

The hauling limitations, consequent upon high-wheel, high sustained power locomotives, without excessive wear and tear of machinery, and undue delay in accelerating frequently become the starting load rather than the road hauling load. An auxiliary power medium permits the locomotive to accelerate promptly and start a train, which is well within the ability of the locomotive to handle after once under way. Early attempts at auxiliary power utilization as previously mentioned, wholly aside from any inherent structural weaknesses, failed due to the limitations of steam production.

The growth in the size and capacity of locomotives has resulted in a boiler of proportions, such that a reserve capacity is available at slow speeds for auxiliary power use. The boiler of a locomotive in its design must be considered in relation to the steam requirements at speed of the cylinders. Generally considered, experience has shown that maximum steam requirements and maximum horsepower for superheated-steam locomotives occur around a piston speed of 1000 ft. per min. Simply stated, this fundamental concept in auxiliary power use is as shown in Fig. 2.

It is this surplus boiler capacity which can be drawn upon, as reflected in road and test-plant results, and utilized in the operation of an auxiliary power medium. The Bethlehem auxiliary locomotive is a self-contained auxiliary power truck, which can replace one of the regular tender trucks. It can be used either as a front or back truck or in some instances to replace both. Ordinarily the rear-truck installation is recommended as this facilitates removal for inspection and maintenance.

A tender-truck installation of an auxiliary power medium results generally in a most satisfactory employment of such additional power. Being gear driven and operated under a wide open throttle, an auxiliary power medium requires a higher factor of adhesion than a locomotive where power output can be graduated by throttle manipulation. The weight of modern tenders is such that a very ample and high factor of adhesion results, giving a unit which permits maximum possible power development and reliable operation, free from slipping.

This advantage is particularly apparent where the auxiliary-

[1] Bethlehem Steel Company.

Contributed by the Railroad Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

locomotive steam pipe is independently connected to the superheater header on locomotives equipped with front-end throttles. In this case the auxiliary power unit is not affected when the main locomotive slips, and since with a high factor of adhesion it is not subject to slippage, it serves a very useful purpose in at least keeping the slack stretched while quieting down the main engine, and has frequently been the means of avoiding stalling under such conditions.

A tender application has the advantage of converting a large, essential non-productive weight into a valuable supplementary power source without sacrificing its primary purpose. At the same

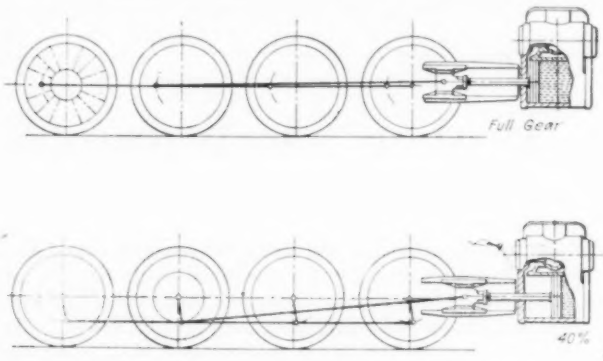


FIG. 2 FUNDAMENTALS IN AUXILIARY POWER USE

Cylinder volume	V	V
Steam per cylinder filling	V	$40/100\ V$
Speed, m.p.h.	10	35
Corresponding piston speed for 32-in. stroke and 63 in. wheel	284.5 ft. per min.	996 ft. per min.
Steam requirements per hour proportional to miles per hour times steam per cylinder filling.		
Requirements per hour	$10\ V$	$14\ V$
Relative requirements	71 per cent	100 per cent

time it permits full utilization of the physical limitations of railroad clearances and rail loads in the development of the maximum boiler capacity and locomotive power.

Utilizing the idle truck axles of the locomotive tender for supplementary power will accomplish the following:

1 It will add to the locomotive drawbar pull from 15 per cent to 35 per cent depending upon the size of the locomotive unit.

2 This added capacity permits a corresponding increase in train tonnage where starting ability governs or where the ruling grade is a somewhat limited portion of the operating division.

3 It provides for increase in train tonnage where bridge and rail limitations restrict locomotive weight and therefore tractive power.

4 It accomplishes the equivalent of grade reduction for purposes of equalizing grades, but with less capital expenditure.

5 Curvature on heavy grades can be compensated by auxiliary power use on all curves.

6 It permits increase in average speed over grades where the added drawbar pull is not wholly utilized for handling tonnage.

7 It provides more prompt and constant acceleration from yard, water station, and enforced signal stops.

8 It reduces locomotive slipping in starting, and therefore tire and rail wear.

9 It provides more uniform drawbar pull which results in a decrease in abnormal starting stresses on draft gears and equipment.

Considering the various features of train operation, it is clear that the use of an auxiliary power unit which can be operated independently so as to be available when required for assisting the locomotive in starting the train, and permitting considerable increase in train tonnage than otherwise could be handled, is closely related to economical train operation.

While railroad operation involves so many kinds of profiles and traffic conditions that no fixed rules can be laid down to indicate the various power arrangements that would be most efficient with respect to utilization of auxiliary power and regular helper service, there are few operations to which the auxiliary locomotive cannot be adapted on a very profitable basis.

Where ruling grades are relatively short (momentum or otherwise), the use of an auxiliary power unit permits increasing the train tonnage an amount over the entire division consistent with that for a locomotive of the tractive power of combined auxiliary and main locomotive tractive power.

Where the ruling grade is compensated by means of assistant or helper-engine service, the next heaviest grade of the district then becomes the ruling grade, and where conditions warrant, tonnage rating can be arranged with reference to the capacity of the main locomotive and auxiliary locomotive on the secondary grade. A condition such as the foregoing would undoubtedly require auxiliary power use in negotiating the primary ruling grade, and might require auxiliary power use on helper locomotives if sufficient differential existed in gradient.

Operating conditions with heavy pusher ruling grades, which do not present long continuous uniform gradients, afford opportunity for increasing train tonnage through use of an auxiliary power medium applied only to the helper locomotives.

Low-grade operating divisions permitting high-speed operation and adaptable to high capacity, large driving-wheel power can, as previously outlined, be negotiated by increased tonnage trains through the use of the auxiliary power unit to start and accelerate the train.

Many locomotives have sufficient boiler capacity to support two auxiliary locomotives where only short periods of operation of the auxiliary units are required. This is especially an important feature in regard to hump engines, so as to permit handling trains with a single locomotive without the necessity of cutting trains for handling.

Dynamometer-car tests were run on the Boston and Maine Railroad during the spring of 1927, which give a very good picture of what can be accomplished under service conditions.

The tests were run between Mechanicsville, N. Y., and East Deerfield, Mass., over the Berkshire division of the Boston and Maine Railroad. In both directions, there is an up grade operation to the Hoosac tunnel piercing the Hoosac Mountains, and through which trains are handled by electric locomotives.

A comparative picture of road operation on the section between Mechanicsville and Hoosick Falls as revealed by these dynamometer tests is shown in the chart Fig. 6. This gives the profile of the section, and at the bottom are figures for the average developed drawbar pull, the speed at the mile posts, and the running time between certain points for east bound operation. This graphic picture serves to show the increased drawbar pull required under varying road conditions, handling an increase in tonnage, justified by the supplementary use of the Bethlehem auxiliary locomotive to handle such tonnage over the ruling grade.

In demonstrating the value of the auxiliary locomotive as well as to answer satisfactorily whether tonnage could be handled, all test trains whether locomotive tonnage only or extra auxloco tonnage trains, were stopped on the ruling grade at the worst operating condition and handled from there. Further, all extra auxloco tonnage trains were started only with the use of the auxiliary locomotive to supplement the locomotive after three stalling starts were made with the locomotive only. Westbound stops were made for signal 1157, just east of mile post 116, and east bound stops for signal 1179, just west of mile post 180.

Regular stops were made at the east and west portal for electric locomotives. Electric locomotives in some east-bound tests were coupled on near mile post 142 at North Adams rather than

TABLE 1 SUMMARY OF BOSTON AND MAINE DYNAMOMETER TESTS

East Bound Operation

	Auxloco tonnage trips				Regular tonnage trips		
	No. 2	No. 4	No. 10	Average	No. 6	No. 8	Average
Feedwater heater or injector	F W H	F W H	Inj.		F W H	Inj.	
Actual tons, incl. dynamometer car and caboose	3403	3502	3496	3467	2962	2952	2957
Loaded cars	62	74	63	66.3	57	63	60
Empty cars	2	8	1	3.7	4	2	3
Total cars	64	82	64	70.0	61	65	63
Allowed mileage trip	85	82	82	..	85	85	..
1000 G.T.M.'s	289.255	287.164	286.672	287.697	251.770	250.920	251.345
Elapsed time h.m.s.	5-51-55	5-53-54	5-57-13	5-54-21	5-31-40	5-43-50	5-37-45
Deductions h.m.s.	0-59-34	1-12-21	1-10-42	1-07-32	0-59-55	1-14-13	1-07-04
Running time h.m.s.	4-52-21	4-41-33	4-46-31	4-46-48	4-31-45	4-29-37	4-30-41
Speed per train hour:							
Elapsed	14.5	13.9	13.8	..	15.4	14.8	..
Running	17.4	17.5	17.2	..	18.8	18.9	..
Coal—working distance	16,352	17,854	21,600	18,602	15,686	16,048	15,867
Total trip	20,554	21,390	24,908	22,284	18,538	20,478	19,508
Coal per 1000 G.T.M.	71.05	74.48	86.88	77.46	73.63	81.61	77.69
1000 G.T.M.'s per train hr.:							
Elapsed time	49,320	48,680	48,150	48,713	45,570	43,790	44,652
Running time	59,350	61,200	60,030	60,188	55,560	55,830	55,718
Running time:							
Mechanicsville—Test MP. 180	0-56-25	0-51-56	0-53-07	0-53-46	0-41-24	0-41-40	0-41-32
Test MP. 180—Eagle Bridge	0-50-16	0-43-46	0-50-19	0-48-07	0-37-23	0-43-47	0-40-35
Eagle—North Adams	1-11-20	1-30-20	1-27-24	1-23-01	1-23-30	1-17-00	1-20-15
Electric operation	0-30-15	0-22-44	0-20-25	0-24-28	0-19-46	0-19-46	0-19-27
East Portal—Greenfield	....	1-12-47	1-15-26	....	....	....	....
East Portal—East Deerfield	1-24-05	....	....	1-17-26	1-30-20	1-27-24	1-28-52
Actual distance, feet:							
Mechanicsville—North Adams	246,885	246,540	250,869.5	248,098	251,587.5	246,920	249,253
Auxloco operation	26,078′	15,576′	33,615′	25,089.7	....	....	....
Time auxloco operation	0-40-46	0-30-03	0-47-35	0-39-28	....	....	....
Per cent auxloco operation:							
Mechanicsville—North Adams	....	....	....	....	....	....	....
Distance, per cent	10.56	6.32	13.4	10.1	....	....	....
Running time	22.85	16.28	24.94	21.65	....	....	....
Average tractive power at 1000 ft. intervals	51,980	52,681	53,200	52,677	44,360	42,616	43,478
Test MP. 180—Eagle Bridge	41,446	40,572	42,240	41,403	33,753	34,390	34,069
Eagle Bridge—North Adams	32,905	35,685	34,913	34,525	30,554	29,141	29,856
Number of stops	5	6	7	6	8	6	7

West Bound Operation

	Auxloco tonnage trips				Regular tonnage trips		
	No. 1	No. 3	No. 9	Average	No. 5	No. 7	Average
Feedwater heater or injector	F W H	F W H	Inj.		F W H	Inj.	
Actual tons, incl. dynamometer car and caboose	2384	2404	2396	2394.7	2091	2066	2078.5
Loaded cars	27	22	22	23.7	5	17	11
Empty cars	54	69	75	66.0	86	73	79.5
Total cars	81	91	97	89.7	91	90	90.5
Allowed mileage trip	84	84	84	....	84	84	....
1000 G.T.M.'s	200.256	201.936	201.264	201.152	175.644	173.544	174.594
Elapsed time, h.m.s.	5-52-20	6-49-02	6-10-56	6-17-26	5-04-10	5-02-47	5-03-28
Detentions	1-06-41	1-48-00	1-10-25	1-21-42	0-37-50	0-51-31	0-44-40
Running time	4-45-39	5-01-02	5-00-31	4-55-44	4-26-20	4-11-16	4-18-48
Speed per train hour:							
Elapsed time	14.3	12.3	13.6	....	16.6	16.6	....
Running time	17.6	16.8	16.8	....	18.9	20.0	....
Coal—Working distance	11,712	12,530	15,210	13,151	10,952	11,560	11,256
Total trip	16,522	17,796	21,010	18,442.7	15,154	16,522	15,838
Coal per 1000 G.T.M.	82.50	88.12	104.39	91.68	86.27	95.38	90.71
1000 G.T.M.'s per train hr.:							
Elapsed time	34,105	29,620	32,560	32,979	34,650	34,400	34,518
Running time	40,150	40,250	40,180	40,809	39,570	41,420	41,690
Running time:							
East Deerfield—Test Sig. 1157	0-55-00	1-04-56	0-52-37	0-57-31	0-47-38	0-50-04	0-48-51
Test to East Portal	1-20-35	1-20-02	1-44-21	1-28-19	1-20-31	1-16-37	1-18-34
Electric operation	0-25-00	0-29-25	0-25-52	0-26-46	0-21-25	0-23-00	0-22-13
North Adams—Mechanicsville	2-05-04	2-06-39	1-57-41	2-03-08	1-56-46	1-41-35	1-49-10
Actual distance—ft.:							
East Deerfield—East Portal	166,212	165,953	165,543	165,903	168,718	167,860.5	168,289
Auxloco operation	18,551	22,804	22,584	21,313	....	....	....
Time—Auxloco operation	0-29-18	0-36-13	0-44-17	0-36-36	....	....	....
Per cent auxloco operation:							
East Deerfield to East Portal							
Distance	11.16	13.75	13.62	12.86	....	....	....
Running time, per cent	21.55	25.03	28.17	26.93	....	....	....
Average tractive power at 1000 ft. intervals:							
East Deerfield to test	30,840	34,630	35,005	33,478	30,338	29,965	30,153
Test to MP. 120	59,785	62,615	65,010	62,510	54,390	54,123	54,257
MP. 120 to East Portal	31,680	33,955	38,405	34,653	31,710	29,970	30,824
No. of stops	5	7	6	6	5	4	4.5

at the portal. A stop was also made on all east-bound trips at Eagle Bridge for a non-interlocked crossing. Other extra stops are indicated on the chart.

East-bound traffic is of major importance on tonnage trains, being the prevailing movement. The operation in this direction shows an increase in the gross ton mile per train hour, the average being 60,188 for auxloco-locomotive operation as against 55,718 for engine only, an increase of 8 per cent.

West bound there was a slight loss in gross ton miles per train hour, an average 40,809 being secured under extra tonnage operation compared with 41,690 under regular operation, a loss of 2.2 per cent. Table 1 gives test summaries.

No difficulty was experienced at any time in maintaining the steam pressure on the locomotive during the time the auxiliary locomotive was in operation. The log of boiler, steam-chest, and auxiliary steam-chest pressures as well as water-level, superheat, and reverse-lever position are given in Table 2 for test No. 3 over the section from the start at signal 1157, MP. 116 to MP. 120 with the auxiliary locomotive operating over the entire section. The reason for the drop in pressure at the last reading was to avoid lifting the safety valve after the engine was partly shut off passing MP. 120.

The dynamometer charts which were made but are not included in this paper illustrate the value of an auxiliary locomotive. Entering Soapstone siding, the locomotive ordinarily could handle the train, but in rounding the S curve just beyond the switch entrance, a bad rail condition was encountered owing to water dropping from a ledge of rocks on to the right-hand rail, the

TABLE 2 LOG OF TEST NO. 3

Time	Pressure: Boiler	Pressure: Steam chest	Pressure: Auxloco	Water level: Glass	Superheat	Reverse lever
10-08-30	193	180	175	3/8	540	30
10-09-36	185	167	150	1/2	550	30
10-14-30	187	170	150	1/2	570	28
10-18-35	185	172	150	3/8	590	25
10-27-05	185	168	150	3/8	590	25
10-29-18	187	165	150	3/8	580	20
10-34-20	185	170	150	3/8	580	20
10-35	184	163	150	1/2	580	25
10-38-30	188	165	150	1/2	580	23
10-41	183	168	150	1/2	575	23

locomotive slipped badly upon reaching this strip. The speed was reduced from 7½ m.p.h. to 3 m.p.h. in 45 sec., and the locomotive would have stalled except for the fact that the auxiliary locomotive was cut in, and within a distance of slightly over 1200 ft. accelerated the train from 3 m.p.h. to 8.4 m.p.h.

A typical use of the auxiliary locomotive to accelerate a train on a grade, and at the same time compensate for curvature on the grade was while a train was being handled on a 0.47 per cent grade. The engine had just started on to a short tangent beyond the last curve, so that the train was being handled around a number of curves. The use of an auxiliary locomotive in handling increased tonnage over a heavy grade is shown in a typical start with a regulation tonnage train from signal 1157, east of MP. 116

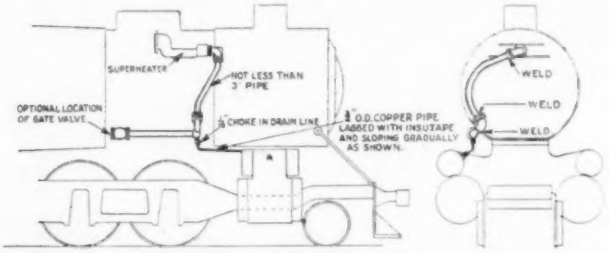


FIG. 3 AUXILIARY LOCOMOTIVE STEAM-PIPE CONNECTIONS TO SUPERHEATER WHERE FRONT-END THROTTLE IS USED

using the locomotive only, and the starting of an auxiliary locomotive extra-tonnage train from the same point. An additional drawbar pull of 10,000 lb. was needed to start this train over that which the locomotive alone developed in a stalling start. A steadier pull was secured through the use of the auxiliary locomotive added to that of the main locomotive, and there was a decreased tendency of the main locomotive to slip.

Use of the auxiliary locomotive is shown in Table 3 which gives the acceleration while handling of regulation tonnage from signal 1798 near MP. 180. These records also serve to show the relative accelerating ability of the locomotive equipped with the auxiliary locomotive where the use of the auxiliary is continued beyond the point absolutely required to handle the extra tonnage train.

TABLE 3 ACCELERATION FROM START SIGNAL 1798

Test number	Distance from start, ft.	Time from start, sec.	Speed, m.p.h.
Engine and Auxloco			
2	1000	147	6.5
	2000	244	7.9
4	1000	167	7.0
	2000	255	8.6
Engine only			
6	1000	190	6.3
	2000	285	8.7
8	1000	169	6.9
	2000	259	7.3

The use of an auxiliary locomotive from a bad water-plug stop is presented by the operating conditions at Johnsonville, where the train is on a 0.55 per cent grade, and the engine dips over the crest of the hill and starts down a 0.39 per cent grade.

It is evident in the foregoing that the locomotive boiler fundamentally determines the utility of an auxiliary power medium. While a given locomotive boiler has a definite evaporative capacity, it must be conceded that this capacity cannot under present locomotive design be availed of at all speeds.

Stephenson in the early stages of locomotive development conceived the idea of employing the exhaust steam in a blast for the purpose of drafting the locomotive. This principle is still employed, and with the employment of the most efficient appliances represents a nearly ideal method for ordinary operation.

Draft is a function of combustion rate, and also of steam consumption and therefore exhaust, and the variation in the combination of variables is such that as an increased firing rate becomes necessary, the increased steam consumption and therefore the exhaust increases the draft so as to support the higher firing rate.

It must therefore follow that under certain conditions, the increased boiler capacity required for auxiliary power use must result from forcing the boiler beyond the normal capacity for that



FIG. 4 TYPICAL INSTALLATION ON AN ENGINE OF U.S.R.A. HEAVY MIKADO DESIGN, DOME THROTTLE APPLICATION

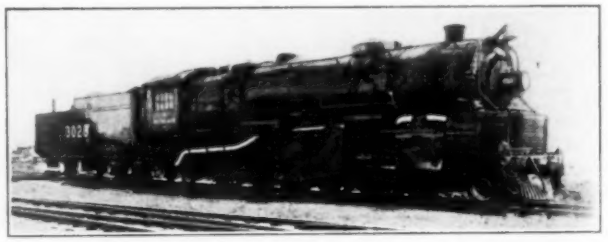


FIG. 5 BOSTON AND MAINE "SANTA FE" USED IN DYNAMOMETER TESTS

(Cylinder size 29 in. diam. × 32 in. stroke—Driving wheels 61 in. diam.—Boiler pressure 190 lb.—Locomotive tractive power 71,300 lb.—Weight on drivers 307,500 lb.—Total locomotive weight 368,000 lb.—Weight of tender with auxloco 230,400 lb.—Heating surface, tubes 3161 sq. ft., flues 1330 sq. ft., firebox 250 sq. ft. arch tubes 525 sq. ft., total heating surface 4793.5 sq. ft.—Superheating surface 1114 sq. ft.—Feedwater heater, Worthington—Tender capacity 12,000 gallons of water, 16 tons of coal.)

condition of working. Many attempts have been made to develop methods of induced and forced draft which will have the effect of making the boiler independent of engine working, and with the successful development of any such method, a greatly extended field for auxiliary power utility will be opened up.

Having in mind the limitations of boiler output under present conditions and the effect of such on the use of an auxiliary power unit, as well as the complete development of the value of an auxiliary power medium, the use of the Pennsylvania Railroad's locomotive test plant at Altoona was obtained and comprehensive tests were run of the locomotive and Bethlehem auxiliary locomotive, alone and together.

These tests were conducted with the auxiliary locomotive working alone, and also working in operation with a locomotive as it is applied in actual service. Owing to the limited length of the testing plant, it was impossible to test the auxiliary locomotive as one of the tender trucks. It was, therefore, applied in place of the trailer truck to a 2–8–2 type locomotive (Pennsylvania class

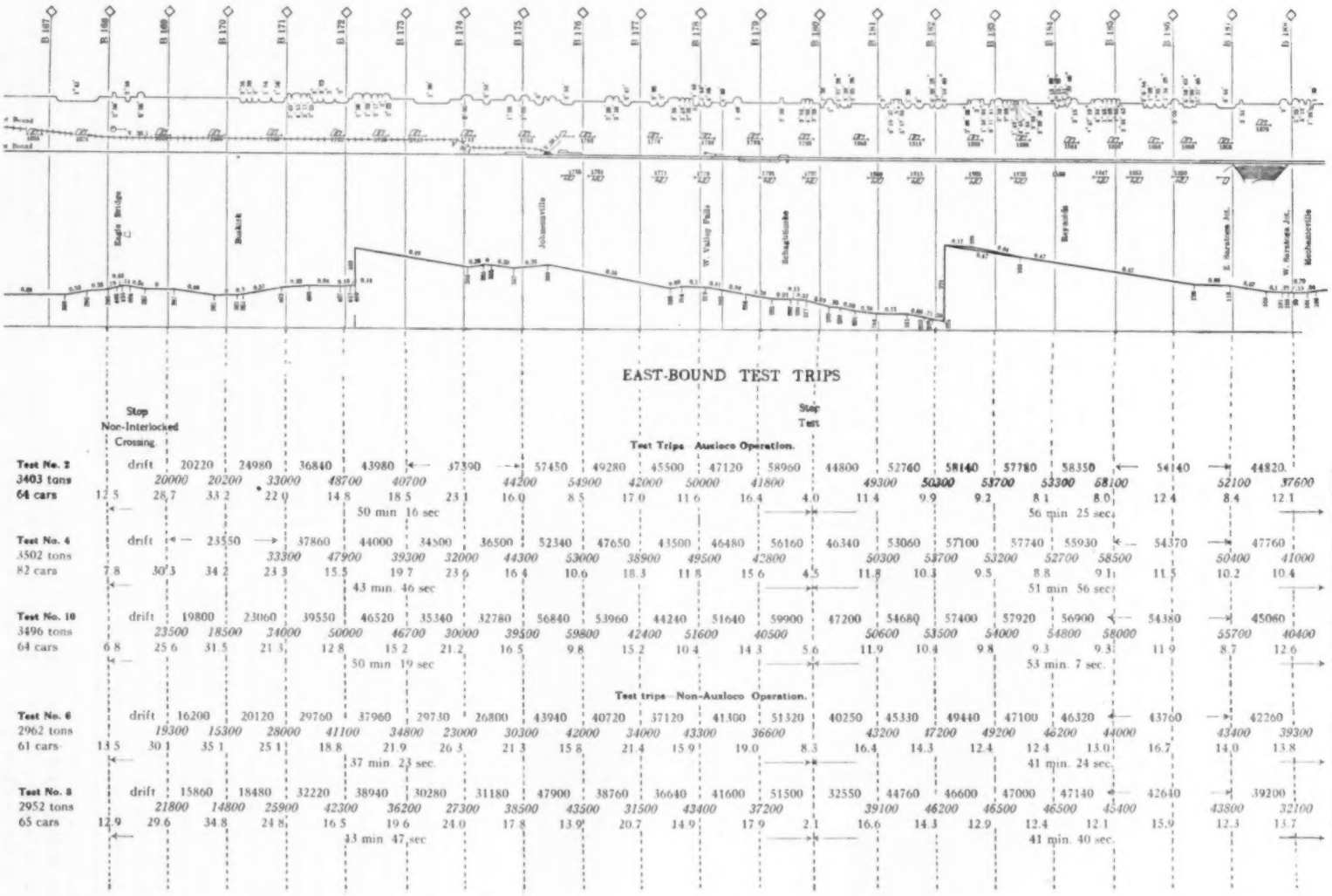

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E Bound
W Bound
Eagle Bridge
Buskirk
Johnsonville
W. Valley Falls
Schaghticoke
Reynolds
E. Hoosick Jct.
W. Hoosick Jct.
Mechanicville
EAST-BOUND TEST TRIPS
Stop
Non-Interlocked
Crossing
Stop
Test
Test Trips Auxiloco Operation.
Test No. 2
3403 tons
64 cars
drift 20220 24980 36840 43980 ← 37390 → 57450 49280 45500 47120 58960 44800 52760 58140 57780 58350 ← 54140 → 44820
20000 20200 33000 48700 40700 44200 54900 42000 50000 41800 49300 50300 53700 53300 58100 52100 37600
12.5 28.7 33.2 22.0 14.8 18.5 23.1 16.0 8.5 17.0 11.6 16.4 4.0 11.4 9.9 9.2 8.1 8.0 12.4 8.4 12.1
50 min. 16 sec
56 min. 25 sec.
Av. T.P. at
1000' intervals
T.P. at Mile Posts
Running Time
Test No. 4
3502 tons
82 cars
drift ← 23550 → 37860 44000 34500 36500 52340 47650 43500 46480 56160 46340 53060 57100 57740 55930 ← 54370 → 47760
33300 47900 39300 32000 44300 53000 38900 49500 42800 50300 53700 53200 52700 58500 50400 41000
7.8 30.3 34.2 23.3 15.5 19.7 23.6 16.4 10.6 18.3 11.8 15.6 4.5 11.8 10.3 9.5 8.8 9.1 11.5 10.2 10.4
43 min. 46 sec
51 min. 56 sec.
Av. T.P. at
1000' intervals
T.P. at Mile Posts
Running Time
Test No. 10
3496 tons
64 cars
drift 19800 23060 39550 46520 35340 32780 56840 53960 44240 51640 59000 47200 54680 57400 57920 56900 ← 54380 → 45060
23500 18500 34000 50000 46700 30000 39500 59800 42400 51600 40500 50600 53500 54000 54800 58000 55700 40400
6.8 25.6 31.5 21.3 12.8 15.2 21.2 16.5 9.8 15.2 10.4 14.3 5.6 11.9 10.4 9.8 9.3 9.3 11.9 8.7 12.6
50 min. 19 sec
53 min. 7 sec.
Av. T.P. at
1000' intervals
T.P. at Mile Posts
Running Time
Test trips Non-Auxloco Operation.
Test No. 6
2962 tons
61 cars
drift 16200 20120 29760 37960 29730 26800 43940 40720 37120 41300 51320 40250 45330 49440 47100 46320 ← 43760 → 42260
19300 15300 28000 41100 34800 23000 30300 42000 34000 43300 36600 43200 47200 49200 46200 44000 43400 39300
13.5 30.1 35.1 25.1 18.8 21.9 26.3 21.3 15.8 21.4 15.9 19.0 8.3 16.4 14.3 12.4 12.4 13.0 16.7 14.0 13.8
37 min. 23 sec.
41 min. 24 sec.
Av. T.P. at
1000' intervals
T.P. at Mile Posts
Running Time
Test No. 8
2952 tons
65 cars
drift 15860 18480 32220 38940 30280 31180 47900 38760 36640 41600 51500 32550 44760 46600 47000 47140 ← 42640 → 39200
21800 14800 25900 42300 36200 27300 38500 43500 31500 43400 37200 39100 46200 46500 46500 45400 43800 32100
12.9 29.6 34.8 24.8 16.5 19.6 24.0 17.8 13.9 20.7 14.9 17.9 2.1 16.6 14.3 12.9 12.4 12.1 15.9 12.3 13.7
43 min. 47 sec
41 min. 40 sec.
Av. T.P. at
1000' intervals
T.P. at Mile Posts
Running Time

FIG. 6

L–1–s). The steam supply pipe to the auxiliary locomotive was connected to both branch pipes of the locomotive. The usual number of bends and Barco joints were placed in the steam line to give the same length of pipe and resistance to steam flow, as if the auxiliary locomotive were placed in its normal location under the tender. The gears were blocked in mesh. The weight supported by the auxiliary locomotive was not ascertained, but it was sufficient to prevent slipping of the wheels.

The first tests were made for the purpose of comparing the results obtained with the locomotive working alone, and when assisted by the auxiliary locomotive. These preliminary tests were made at speeds of 40, 50, and 60 r.p.m., which correspond to 7.3, 9.2, and 11 m.p.h. respectively.

Full gear tests of the locomotive at 80 per cent cutoff were made at all three speeds, while tests at 60 and 70 per cent cutoff were made at speeds of 7.3 and 11 m.p.h. Special tests of the

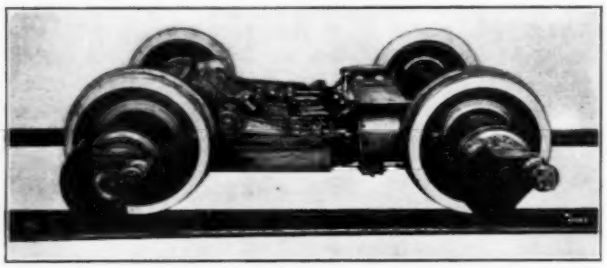


FIG. 7 BETHLEHEM AUXILIARY LOCOMOTIVE WITH TRUCK FRAME REMOVED SO AS TO REVEAL OPERATING MECHANISM

(Diameter truck wheels 36 in.—Cylinders 12 in. diameter 10 in. stroke—Gear ratio 1 to 2.25—Cylinder clearance 11/32 in. on each end—Piston valves inside admission, diameter 4 1/2 in.—Valve travel 3 1/4 in.—Valve lead 1/32 in.—Valve steam lap 7/8 in.—Valve exhaust lap, line and line—Cut off approximately 70 per cent—Weight of auxiliary locomotive approximately 31,500 lb.—Normal tractive power—72 × boiler pressure.)



FIG. 8 BASIC U.S.R.A. LIGHT MIKADO DESIGN WITH INDEPENDENT STEAM-PIPE CONSTRUCTION

locomotive alone were made to show the change in drawbar pull at 7.3 and 11 m.p.h. with various changes in cutoff. Tests were also made to determine the steaming capacity of the locomotive. In addition a series of tests of the auxiliary locomotive were made to determine its characteristics when operated alone.

All the tests, except those conducted on the auxiliary locomotive alone were made in pairs. In other words, a test of the locomotive and the auxiliary locomotive was followed by a test of the locomotive alone, the test of the locomotive alone starting as soon after the auxiliary locomotive was stopped as the firing rate, rate of boiler feed, branch pipe temperature, etc., became adjusted to the new test conditions. The locomotive and auxiliary when operated together were run at the same speed in miles per hour. Tests of the auxiliary locomotive alone were made at speeds lower than when it was operated with the locomotive. Starting tests were not attempted either with the locomotive or auxiliary locomotive on account of the danger of slipping.

The diameters of the driving wheels of the locomotive were 62 in., and that of the auxiliary locomotive driving wheels, 36 in. The gear ratio of the auxiliary locomotive used in these tests was 2.25. The locomotive was hand fired with run-of-mine bituminous coal. The factor of primary importance to the railroad man developed by these tests is "what does it add in hauling capacity?" Table 4 shows the drawbar pull of the locomotive alone and the locomotive and auxiliary locomotive operated together:

TABLE 4 DRAWBAR PULL ABOVE MAXIMUM OF LOCOMOTIVE

	Drawbar pull—pounds			
Speed, m.p.h.	Locomotive alone	Locomotive with auxiliary locomotive	Difference between locomotive with auxiliary and locomotive alone	Cutoff of locomotive per cent
7.3	58,669	69,111	10,442	Full gear
7.3	56,425	68,615	12,190	80
9.2	55,740	66,184	10,444	80
11.0	53,838	63,433	9,595	80
7.3	51,679	63,121	11,442	70
7.3	47,244	57,689	10,445	60

These tests were made at three speeds, 7.3, 9.2, and 11.0 m.p.h. At 7.3 m.p.h. it was possible to operate both the locomotive in full gear, and also the auxiliary locomotive, giving a combined drawbar pull of 69,111 lb. The locomotive blower was required in this test to maintain boiler pressure.

No full-gear tests with the auxiliary locomotive in use were made at speeds above 7.3 m.p.h. As full boiler pressure was maintained in the test in full gear at 7.3 m.p.h. with auxiliary, it is probable that the locomotive could have been worked in full gear with the auxiliary in use at a slightly higher speed.

When operated together, the drawbar pull is less than the sum of the drawbar pulls of each individual unit under the same test conditions due to the greater drop in steamchest pressure. This difference increases as the speed increases. The minimum speed at which the locomotive was run in these tests was 40 r.p.m., or 7.3 m.p.h., and it is probable that at lower speeds the total drawbar pull would approach the sum of the drawbar pulls of the two units, and very nearly if not equal it at starting speeds.

While Table 4 shows the increase in drawbar pull due to the auxiliary locomotive, for various test conditions, it does not show either the maximum pull of the locomotive alone, or the net increase due to the auxiliary locomotive, except at the lower speed of 7.3 m.p.h.

Tests of a class L–1–s locomotive, as recorded in P.R.R. Bulletin 28, show maximum pulls at other speeds, and tests were made of locomotive No. 1306 to confirm the results shown there. These are tests at 50 r.p.m., 9.2 m.p.h., and full gear cutoff, and at 60 r.p.m., 11.0 m.p.h., and full gear. The drawbar pulls obtained are shown in Table 5 which also shows the net increase in pull, due to the auxiliary locomotive.

The pulls of 66,184 lb. and 63,433 lb. at 9.2 and 11.0 m.p.h. were not made with the locomotive in full gear, but at 80 per cent cutoff. It may be that a slightly greater pull is possible at 9.2 m.p.h. In this test, while the blower was used, the boiler pressure was easily maintained. The pull at 11.0 m.p.h. is a maximum as, in this test, the blower was used, and the pressure was not fully maintained throughout the test.

In the plotted results shown on Fig. 9 the drawbar pull of the locomotive and auxiliary at 9.2 m.p.h. falls on the curve and, therefore, it is probable that the net increase shown is the maximum obtainable for not only 7.3 m.p.h., but also for 9.2 and 11.0 m.p.h.

TABLE 5 INCREASED PULL DUE TO AUXILIARY LOCOMOTIVE

	Maximum drawbar pull, lb.		Net increase in pull due to auxiliary locomotive	
Speed m.p.h.	Locomotive alone	Locomotive and auxiliary locomotive	Pounds	Per cent
7.3	58,669	69,111	10,442	17.8
9.2	57,084	66,184	9,100	15.9
11.0	55,964	63,433	7,469	13.4

Tests at Long Cutoff

In addition to the tests of the locomotive at 60, 70, and 80 per cent, and full-gear cutoff, tests were made to determine the effect on the drawbar pull line when the cutoff was decreased by small increments from full gear, the speed remaining constant. This was done for two speeds, 40 and 60 r.p.m. or 7.3 and 11.0 m.p.h.

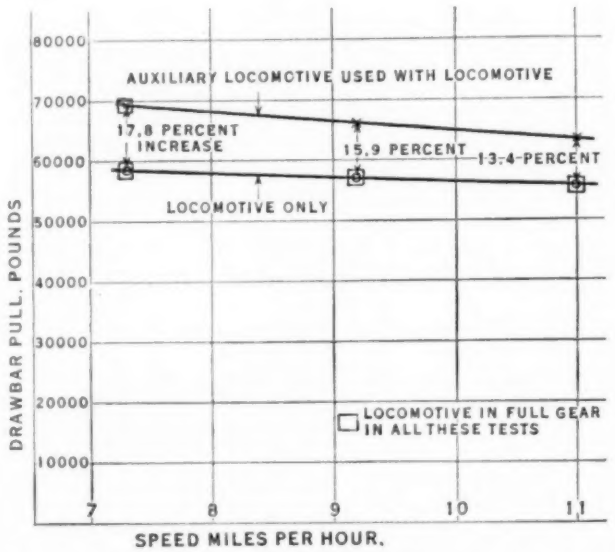


Fig. 9 Maximum Drawbar Pulls With Locomotive Alone and in Combination With Auxiliary Locomotive

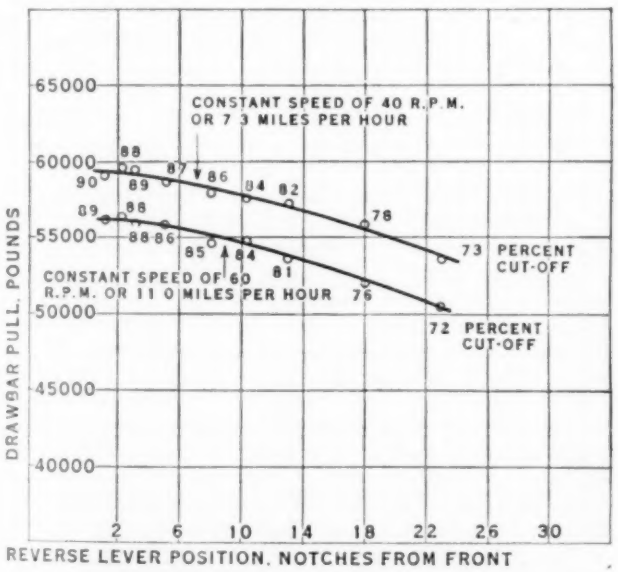


Fig. 10 Drawbar Pull of Locomotive as Effected by Cutoff Adjustment With Constant Speed

The principal data obtained in these tests is shown in Fig. 10. The cutoffs were about evenly spaced in nine notches between 70 per cent and full gear. The drawbar pull falls off as the cutoff is shortened. At 70 per cent cutoff it is about 10 per cent less than in full gear, and at 80 per cent cutoff 4 per cent less for both speeds.

The steam per indicated horsepower-hour was not measured in these tests, as the time of running, in each cutoff, was not long enough. This figure has been calculated from the heat apparently utilized in the cylinders, the quantity of heat being derived from the live- and exhaust-steam pressures and temperatures.

Having learned what is secured by auxiliary locomotive use,

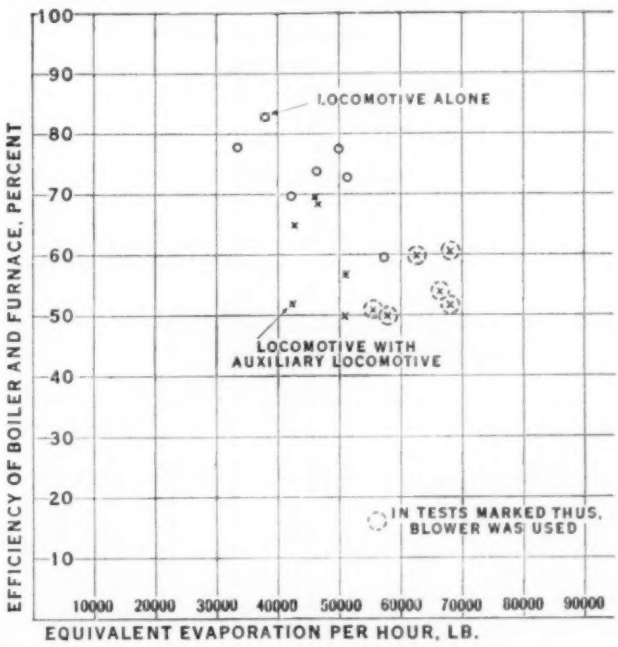


Fig. 11 Boiler Efficiency

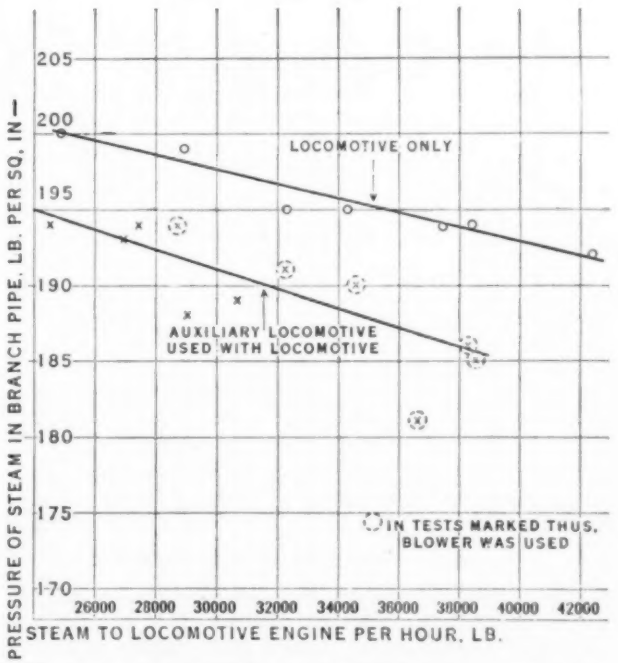


Fig. 12 Branch-Pipe Pressure With Relation to Steam Consumption per Hour

the next natural question is how is it obtained? Full boiler pressure of 200 lb. or above was maintained in all of the tests of the locomotive when operated alone. When the auxiliary locomotive was used in combination with the locomotive, the steam pressure could be maintained up to an equivalent evaporation of 50,000

lb. per hr. Beyond this evaporation rate the blower was necessary. It was not used in test No. 8220, where the evaporation was 56,820 lb. per hour, but this test shows a low boiler pressure,

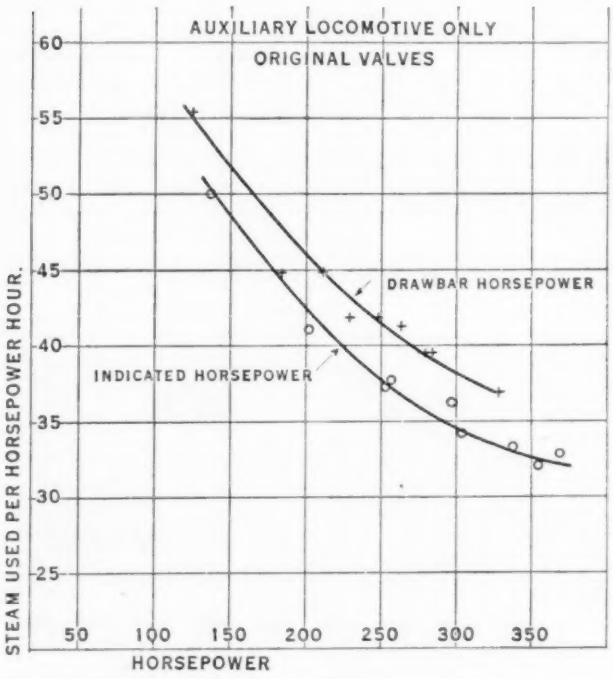


FIG. 13 AUXILIARY LOCOMOTIVE STEAM PER INDICATED HORSE-POWER-HOUR, ORIGINAL VALVES

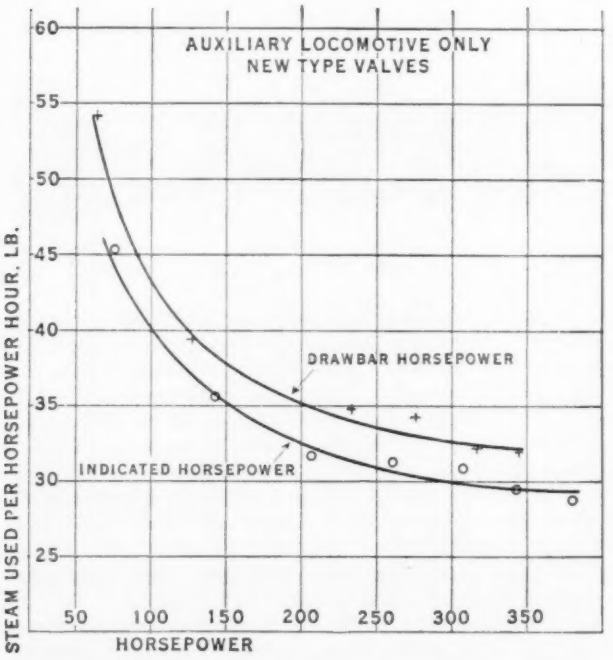


FIG. 14 AUXILIARY LOCOMOTIVE STEAM PER INDICATED HORSE-POWER-HOUR, NEW VALUES

indicating that the blower was needed in a test at this rate of working, with the auxiliary locomotive in use. Because of the low boiler pressure of test No. 8220, the results of this test are omitted on the plotted diagrams.

When operating the locomotive at long cutoffs in conjunction with the auxiliary, the demand for steam exceeds the ability of the boiler to supply it, with the draft available, except at the lower

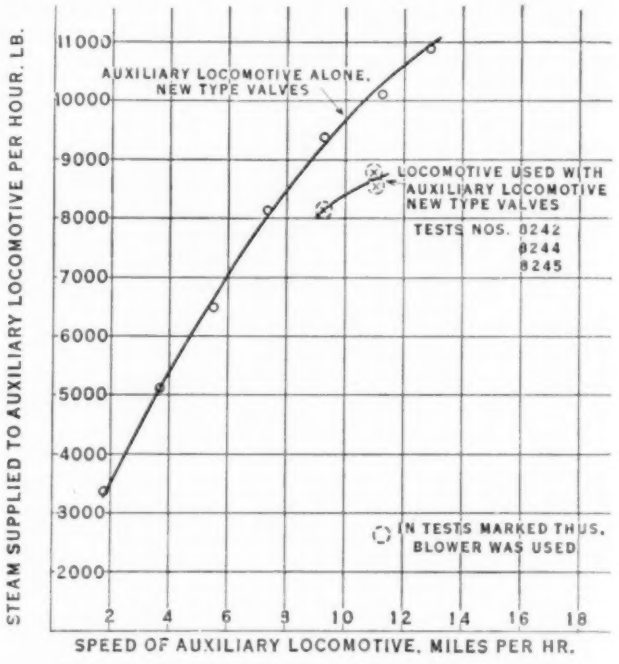


FIG. 15 AUXILIARY LOCOMOTIVE STEAM CONSUMPTION

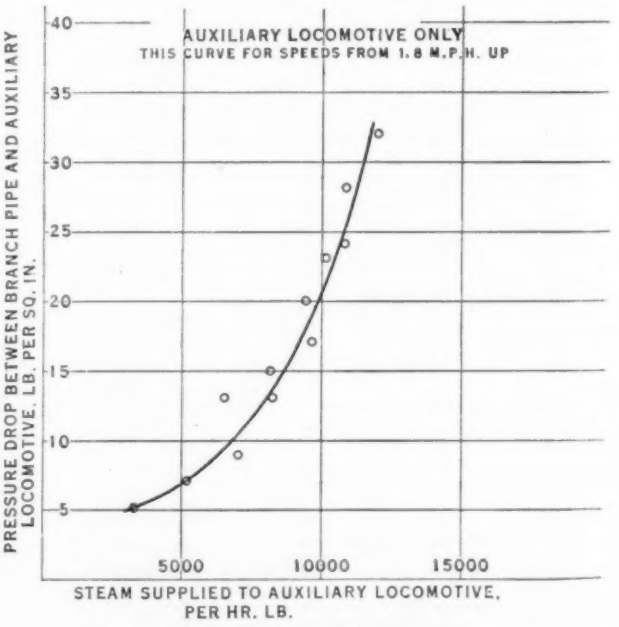


FIG. 16 PRESSURE DROP IN MAIN STEAM PIPE AUXILIARY LOCOMOTIVE

speeds. The available draft can be augmented to some extent by the use of the blower, but not sufficiently to attain the maximum evaporative capacity of the boiler at low speeds.

This forcing of boiler evaporative output naturally results in a lowered thermal efficiency of the whole unit. In full gear at 7.3 m.p.h. the locomotive has an efficiency of 4.9 per cent. When working in full gear in combination with the auxiliary locomotive the efficiency of the unit falls to 3.1 per cent.

When it is realized that the use of an auxiliary poweir unt is required for only a short portion of the operating time for the locomotive, while the benefits of its extra hauling capacity are realized for the whole operating time, this factor becomes of minor importance, except in the general relation of the steam locomotive thermal efficiency.

Boiler Efficiency

The boiler efficiencies at the different rates of evaporation were plotted on Fig. 11, and it was found that the efficiencies are higher for the locomotive alone. With one exception they are above 70 per cent. When the auxiliary is operating with the locomotive and the blower not used, the efficiency is from 50 to 70 per cent, and not in line with the efficiency of the locomotive alone. When the blower is used and normal draft conditions are restored, the efficiency is found to be nearly normal for the output of the boiler, which output, of course, is greater with the auxiliary in use. These tests were of such short duration that figures in regard to coal are not reliable and show scattering points on the diagram when plotted.

Steaming of Locomotive

In order to determine if the locomotive used in the tests was steaming freely, and would develop as high a total evaporation rate per hour as has been found in other class L–1–s locomotives, a test was made at 160 r.p.m. and 65 per cent cutoff. No difficulty was experienced in maintaining a steam pressure of over 200 lb. with an evaporation rate of 61,841 lb. per hour (81,917 lb. equivalent evaporation per hour); a combustion rate of 12,662 lb. of coal per hour, and a steam temperature of 621 deg. fahr. P.R.R. Bulletin No. 28, "Tests of a Class L–1–s Locomotive," shows a test having a maximum evaporation of 57,460 lb. per hour (78,071 lb. equivalent evaporation per hour) with a steam temperature of 618 deg. fahr., using a long superheater, such as the one on locomotive No. 1306. By this comparison, locomotive No. 1306 with a long superheater was shown to be in good steaming condition.

Branch Pipe Pressure and Temperature

Table 6 shows branch-pipe pressures and temperatures for the various test conditions when operating the locomotive alone, and also with the auxiliary locomotive. The pressures are also plotted on Fig. 3. In the table, tests under like conditions are averaged, but the graph shows results for each test separately. It will be noted that the operation of the auxiliary locomotive causes an average reduction in the branch-pipe pressure of five pounds. In this table, averages are shown where there are two tests under like test conditions.

Similarly, the pressure of the steam supplied to the auxiliary locomotive is subject to a greater drop when the locomotive is operated than when the auxiliary is operated alone. When tests are compared under like conditions with and without the auxiliary locomotive, it is found that there is a difference in the average steam temperature of about five degrees, see Table 6. The steam is at a higher temperature with the auxiliary locomotive in operation.

The indicated horsepower of the locomotive, when the auxiliary locomotive is operating, shows the effect of the lower branch-pipe pressure, and is somewhat less at all speeds than when the auxiliary is not used.

The steam per indicated horsepower-hour averages about $1^1/_2$ lb. less when the auxiliary is in use. The reduction in water rate of the main engines when the auxiliary is in use seems rather large for the small increase in steam temperature shown. When the auxiliary is in use the boiler is being worked at a higher rate. The temperature of the steam should, therefore, be higher and consequently a reduction in the water rate of the main locomotive engines is to be expected.

TABLE 6 SHOWING BRANCH PIPE PRESSURES AND TEMPERATURES, ALSO LOCOMOTIVE INDICATED HORSEPOWER AND STEAM CONSUMPTION PER I. HP-HR. FOR THE VARIOUS TEST CONDITIONS

	Steam in branch				Locomotive only			
	Pressure		Temperature		Indicated horsepower		Steam per i.hp-hr. lb.	
Test designation	Auxiliary not in use	Auxiliary in use	Auxiliary not in use	Auxiliary in use	Auxiliary not in use	Auxiliary in use	Auxiliary not in use	Auxiliary in use
40-60-F	200	195	564	553	1083	1050	23.1	23.2
40-70-F	199	194	573	570	1147	1140	25.3	23.9
40-80-F	195	192	586	603	1242	1223	26.0	24.4
40-90-F	195	191	581	597	1257	1239	27.3	26.1
50-80-F	194	190	591	602	1528	1497	25.2	23.1
60-80-F	192	184	600	605	1746	1700	24.3	22.3
Total	1175	1146	3495	3530	8003	7849	151.2	143.0
Average	196	191	583	588	1334	1308	25.2	23.8

TABLE 7 STEAM ECONOMY OF AUXILIARY LOCOMOTIVE OPERATED ALONE

			Steam supplied to auxiliary locomotive: Pressure lb. per sq. in.					
Test no.	Duration of test min.	Speed, m.p.h.	In boiler	At auxiliary locomotive	Temperature at auxiliary locomotive	Weight per hr. lb.	Indicated horsepower of auxiliary locomotive	Steam supplied to auxiliary locomotive per i.hp-hr. lb.
40		62	45	49	49	53	74	80
Loco. code								
Auxiliary Locomotive Alone—Original Valves								
8214	10	3.7	202	193	473	7,000	140	49.9
8213	10	5.5	202	189	494	8,215	201	40.9
8210	15	7.3	203	...	513	9,441	253	37.4
8215	10	7.3	202	184	485	9,681	256	37.8
8216	10	9.1	202	178	497	10,835	299	36.2
8211	15	9.2	203	...	519	10,335	303	34.1
8212	15	11.0	203	...	522	11,200	338	33.1
8218	6	11.0	202	...	525	11,033	345	32.0
8217	10	12.8	203	170	518	12,084	369	32.7

TABLE 8 STEAM ECONOMY WITH NEW VALVES

			Steam supplied to auxiliary locomotive: Pressure lb. per sq. in.					
Test no.	Duration of test, min.	Speed, m.p.h.	In boiler	At auxiliary locomotive	Temperature at auxiliary locomotive	Wt. per hr. lb.	Indicated horsepower of auxiliary locomotive	Steam supplied to auxiliary locomotive per i.hp-hr. lb.
40		62	26	45	49	53	74	80
Loco. code								
Auxiliary Locomotive Alone—New Type Valves								
8241	10	1.8	203	198	492	3,414	75	45.5
8238	8	3.7	202	195	507	5,133	144	35.6
8237	10	5.5	201	198	518	6,544	207	31.6
8236	10	7.3	202	187	509	8,177	261	31.2
8246	6	7.3	201	180	522	...	254	...
8235	10	9.2	203	182	510	9,451	308	30.7
8239	10	11.0	201	177	524	10,142	344	29.5
8247	6	11.0	201	173	521	...	334	...
8240	10	12.8	202	173	521	10,970	382	28.7

Steam Economy of Auxiliary Locomotive

In Tables 7 and 8 the pressures, temperatures, and weights of steam supplied to the auxiliary locomotive are shown as are also the horsepowers and water rates of the auxiliary when operated alone. Table 7 is for tests in which the original valves were used, and Table 8 is for tests using the new-type valves. There is a very considerable decrease in the steam per indicated horsepower-hour when using the new type of valve, the amount of decrease ranging from 10 to 29 per cent.

The auxiliary with the new-type valves uses steam at rates between 3400 and 11,000 lb. per hr., when operating between about 2 m.p.h. and 13 m.p.h. The steam used per indicated horse-

TABLE 9 STEAM ECONOMY OF AUXILIARY LOCOMOTIVE WHEN OPERATED WITH LOCOMOTIVE

Test no.	Test designation, r.p.m., cut-off, throttle	Speed, m.p.h.	Steam supplied to aux. loco. Pressure, lb. per sq. in. In boiler	At auxiliary locomotive	Temp. at auxiliary locomotive	Weight per hour lb.	Indicated horsepower of auxiliary locomotive	Steam supplied to auxiliary locomotive per i hp-hr. lb.
40		62	26	45	49	53	74	80
			Loco. code					
8203	40-60-F	7.3	199	...	523	8,654	...	..
8205	40-60-F	7.3	201	...	536	8,380	...	..
8219	40-70-F	7.3	203	178	552	8,418	255	33.0
8227	40-70-F	7.3	201	176	553	8,472	239	35.4
8222	40-80-F	7.3	203	178	597	8,007	244	32.8
8228	40-80-F	7.3	198	172	573	8,099	237	34.2
8231	40-90-F	7.3	202	173	574	8,160	239	34.1
*8244	50-80-F	9.2	202	171	583	8,159	294	27.8
8207	60-60-F	...	199	...	555	10,029	...	....
8220	60-70-F	11.0	188	150	562	9,355	309	30.3
8229	60-80-F	11.0	192	151	590	9,141	293	31.2
*8242	60-80-F	11.0	201	162	584	8,773	328	26.7
*8245	60-80-F	11.0	201	163	599	8,647	330	26.2

* In these tests the new type valves were used. In all other tests shown in this table the original valves were used.

power-hour, is from 45.5 lb. at 1.8 m.p.h. to 28.7 lb. at 12.8 m.p.h. The indicated horsepower of the auxiliary was from 75 at 1.8 m.p.h. to 382 at 12.8 m.p.h.

Most of the tests of the auxiliary locomotive operating in combination with the locomotive were made with the original valve in use. It may be assumed that if the new-type valves had been used in all tests, the steam consumption would have been less than is shown.

In Table 9 the steam per indicated horsepower-hour, of the auxiliary locomotive, when used with the locomotive, is less than when tested alone. This is, no doubt, due to the higher steam temperature when the locomotive is operating.

The drawbar horsepower, steam economy, and machine efficiency of the auxiliary are shown in Table 10. The machine efficiency ranged between 84 and 92 per cent.

TABLE 10 AUXILIARY LOCOMOTIVE ALONE—NEW TYPE VALVES

Test no.	Duration of test, minutes	Speed m.p.h.	Drawbar horsepower	Steam supplied per i.hp-hr. lb.	Drawbar pull lb.	Machine efficiency per cent
40		62	79	81	65	83
8241	10	1.8	63	54.2	13,083	84.0
8238	8	3.7	130	39.5	13,207	90.3
8237	10	5.5	185	35.4	12,617	89.4
8236	10	7.3	234	34.9	12,022	89.7
8235	10	9.2	276	34.2	11,222	89.6
8239	10	11.0	316	32.1	10,760	91.9
8240	10	12.8	345	31.8	10,093	90.3

At a speed of 7.3 m.p.h., the machine efficiency of the locomotive in full gear cutoff is 91.3 per cent and that of the auxiliary locomotive at this speed, as shown in Table 10, is 89.7 per cent.

Heat Transfer in the Locomotive Superheater

By LAWFORD H. FRY,[1] BURNHAM, PA.

The author's method for calculating heat transfer in locomotive flues is applied to determine the heat transfer in the superheater flues and tubes. It is applied to three sets of experimental data obtained from two locomotives on the Altoona locomotive test plant. In each case the firebox temperature and the rate of flow of the gases of combustion through the flues are taken as points of departure. The Fry method is used to calculate the temperature drop along the evaporative flues and along the superheater flues, and the transfer of heat to the evaporative surface of the flues containing the superheater pipes and to the superheater pipes. The results of the calculations indicated are shown in tabular form in comparison with the observed results.

THE present paper extends the author's method for calculating heat transfer in locomotive flues and shows how it can be applied to determine the heat transfer in the superheater flues and tubes.

To illustrate the scope and accuracy of the method, it is applied to three sets of experimental data obtained from two locomotives on the Altoona locomotive test plant. For one locomotive, Class K2sa, No. 877, with a type A superheater, the test represents a high rate of operation with 50,000 lb. of water evaporated per hour, while for the other locomotive, Class M1s, No. 4700, the two tests with 65,000 and 35,000 lb. of water per hour represent, respectively, high and low power. In each of these cases the firebox temperature and the rate of flow of the gases of combustion through the flues are taken as points of departure. The Fry method is used to calculate:

(*a*) The temperature drop along the evaporative flues

(*b*) The temperature drop along the superheater flues

(These together enable the average smokebox temperatures to be computed and compared with those found experimentally)

(*c*) The transfer of heat to the evaporative surface of the flues containing the superheater pipes

(*d*) The transfer of heat to the superheater pipes

(The last item represents the heat used to superheat the steam and can be compared with the amount of superheat found experimentally.)

TABLE 1 COMPARISON OF OBSERVED AND COMPUTED TEMPERATURES

Locomotive, Class	K2sa	M1s	
Locomotive, No.	877	4700	
Rate of evaporation, lb. of steam per hour	50,000	65,000	35,000
Temperatures of gas in degrees fahrenheit:			
Observed at back flue sheet	2,080	2,000	1,200
Computed for front flue sheet, evaporative flues	614	648	512
Computed for front flue sheet, superheater flues	643	532	470
Computed smokebox temperature	625	578	485
Observed smokebox temperature	620	570	510

The results of the calculations indicated are shown in tabular form in comparison with the observed results. Table 1 shows the computed temperature drop in the evaporative and superheater flues and the resulting smokebox temperatures. These are seen to agree very satisfactorily with the observed smokebox temperatures. It is of interest to note the difference in computed temperatures for the evaporative and for the superheater flues. In locomotive No. 877, with the type A superheater, the temperature of the gases at the front flue sheet is found to be 614 deg. fahr. for the $2^1/_4$-in. evaporative and 643 deg. fahr. for the $5^1/_2$-in. superheater flues. That is, the evaporative flues are slightly more effective in taking up heat. The reverse is, however, the case for locomotive No. 4700, with the type E superheater. In this case the gases, in the high-power test, reach the front flue sheet at temperatures of 648 deg. fahr. for the $2^1/_4$-in. evaporative and 532 deg. fahr. for the $3^1/_2$-in. superheater flues. At first sight it may seem inconsistent to find the gases emerging at the lower temperature from the superheater flues in which the heat-receiving surfaces are at a higher temperature. This result is, however, confirmed, at least qualitatively, by such experimental data as are available, and the reasons for it become apparent when the laws governing the transfer of heat are examined. As will be seen from the formulas given later, the rate at which a gas gives up heat to the flue through which it passes varies for a given rate of gas flow, with the ratio p/a where p is the gas-swept perimeter of the flue and a is the cross-sectional area of the flue. It also varies inversely with the temperature of the flue wall. In locomotive No. 877, with the type A superheater, the $2^1/_4$-in. evaporative flues with a p/a ratio of 2.00 would, other things being equal, be slightly less efficient than the $5^1/_2$-in. superheater flues with a p/a ratio of 2.28, but the higher flue-wall temperature of the superheater flues, 505 deg. against 435 deg., more than offsets the effect of the p/a ratio, and consequently the final temperature of the gases is 614 deg. for the evaporative and 643 deg. for the superheater flues. In locomotive No. 4700, on the other hand, the wall temperatures of the two sets of flues are not so far apart, being 485 deg. for the superheater and 431 deg. for the evaporative flues, while the p/a ratio is 3.30 for the superheater and only 2.00 for the evaporative flues. The effective heat transfer due to the high p/a ratio brings the gas temperature at the front flue sheet down to 532 deg. in the $3^1/_2$-in. superheater flues, while the drop in the $2^1/_4$-in. evaporative flues is only to 648 deg. In this connection it may be noted that in the type E superheater the high p/a ratio causes the temperature drop along the flue to be so rapid that the gases fall below the temperature of the superheated steam long before the front flue sheet is reached. From inspection of Table 2, which shows the progressive drop in temperature along the superheater flues, it can be seen that the gases have reached the branch-pipe temperature while still more than 7 ft. from the front flue sheet. That is to say, the last 7 ft., which is more than 35 per cent of the flue length, is not effective in increasing the superheat of the steam in the outgoing superheater pipe.

Table 2, as already indicated, shows the progressive drop of temperature along the superheater flues for the three cases considered. It also shows for each increment of length of the flue the amount of heat taken up by the superheater pipes and by the evaporative surface. By summing up the heat shown to be taken up by all sections, it is possible to compute the total amount of heat taken up by the superheater pipes. This is compared in Table 3 with the amount of heat shown by the tests to be present as superheat. The heat taken up by the superheater expressed as a percentage of the total heat taken up by boiler and superheater is shown in Table 3 to 8.9 per cent by computation and 11.2 per cent by measurement for locomotive No. 877, while for locomotive No. 4700 it is 10.0 per cent as com-

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Contributed by the Railroad Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

puted and 9.8 per cent as measured. This agreement between computation and measurement is, considering the circumstances, extremely satisfactory, and taken in conjunction with the excellent agreement between computed and measured smokebox temperatures gives considerable confidence in the method of computation.

Equations

The fundamental equations used by the author to determine the transfer of heat from a gas to a flue through which it flows derive from the suggestion made by Hedrick and Fessenden[2] that the rate of heat transfer is proportional at any moment to the total amount of heat carried by the gas. This leads to the conclusion that if the flue has a mean wall temperature of t, and if the gas in flowing a distance of x feet drops from a temperature of T_1 to a temperature of T_2, the relation between these temperatures is

$$\text{lolog } T_1/t - Mx = \text{lolog } T_2/t \quad \ldots\ldots [1]$$

where "lolog" means "the logarithm of the logarithm," M is a coefficient derived from the Equation [2], and all temperatures are measured in absolute units.

The author has shown[3] that this equation is widely applicable and that the coefficient M is dependent only on the rate of flow of the gas through the flue, on the perimeter of the flue in contact with the gas, and on the cross-sectional area through which the gas flows. The relation is given by the equation

$$\log M = B - m \log W/p \quad \ldots\ldots [2]$$

where

W = the rate of gas flow in pounds per hour
p = the flue perimeter in inches
B and m = constants for any flue, being determined by the ratio between the perimeter and the area of the flue as shown in Table 4.

These two equations have a somewhat formidable appearance, but are, as a matter of fact, by no means difficult to apply.

TABLE 2 HEAT TRANSFER FROM GAS DURING PASSAGE OF SUPERHEATER FLUES

	Locomotive K2sa, No. 877 (50,000 lb. steam per hr., type A superheater)				Locomotive M1s, No. 4700 (65,000 lb. steam per hr., type E superheater)			
	1	2	3	4	1	2	3	4
			Heat given up by each pound of gas in passing through section				Heat given up by each pound of gas in passing through section	
Flue section measured from back flue sheet	Computed temperature at front end of section, deg. fahr.	Total B.t.u.	To evaporative surface, B.t.u.	To superheater surface, B.t.u.	Computed temperature at front end of section, deg. fahr.	Total, B.t.u.	To evaporative surface, B.t.u.	To superheater surface, B.t.u.
Back flue sheet[a]	2080	..	..	..	2000[a]	..	..	..
0′0″ to 2′0″	1938	40	40	..	1877	36	36	..
2′0″ to 3′0″	1745	57	30	27	1600	78	47	31
3′0″ to 4′0″	1583	45	25	20	1384	62	37	25
4′0″ to 5′0″	1445	40	22	18	1218	44	28	16
5′0″ to 6′0″	1327	31	17	14	1088	35	21	14
6′0″ to 7′0″	1227	27	15	12	982	28	18	10
7′0″ to 8′0″	1141	24	14	10	898	21	14	7
8′0″ to 9′0″	1067	20	12	8	828	19	13	6
9′0″ to 10′0″	1002	16	10	6	772	14	10	4
10′0″ to 11′0″	945	15	9	6	725	12	8	4
11′0″ to 12′0″	896	13	8	5	688	9	6	3
12′0″ to 13′0″	852	11	7	4	655	9	6	3
13′0″ to 14′0″	814	9	5	4	628	7	5	2
14′0″ to 16′0″	748	18	11	7	587	10	8	2
16′0″ to 18′0″	697	13	8	5	556	8	7	1
18′0″ to 20′8″	643	13	9	4	532	5	4	1
Total	...	392	242	150	...	397	268	129

[a] Temperature at back flue sheet is observed.

TABLE 3 COMPUTED HEAT DISTRIBUTION IN BOILER

Locomotive, Class	K2sa		M1s	
Locomotive, No.	877		4700	
Rate of steam production	50,000 lb. per hr.		65,000 lb. per hr.	
Type of superheater	A		E	
	Per pound of total weight of gas, B.t.u.	As per cent of total heat taken up, per cent	Per pound of total weight of gas, B.t.u.	As per cent of total heat taken up, per cent
Heat taken up by various portions of boiler:				
(1) By firebox	287	42.0	434	53.0
(2) By 2¼-in. evaporative flues	239	35.0	134	16.3
(3) By superheater flues:				
(*a*) Evaporative surface	97	14.1	170	20.7
(*b*) Superheater surface	61	8.9	82	10.0
Total	684	100.0	820	100.0
Observed amount of heat required to superheat the steam (this is item 3(*b*) above)	76.5	11.2	80.3	9.8

From Equation [1] it follows that for any given set of operating conditions (that is to say, for a flue of given dimensions, with a fixed initial temperature, and with a given rate of flow of gas through the flue) the temperature at any point along the flue is dependent only on the main coefficient M. This main coefficient, as shown by Equation [2], is determined by the flue dimensions and by the rate at which the gas is flowing through the flue. Its value in any particular case can be found easily by using Table 4, which gives the values for the auxiliary coefficients B and m when the p/a ratio of the flue is known. For example, a 2-in. circular flue with a perimeter $p = 6.28$ in. and an area $a = 3.14$ sq. in., the p/a ratio is 2.00, and from Table 4, $B = 9.053$ and $m = 0.296$ for this ratio. Then from W, the weight of gas flowing through the flue, and p, the flue perimeter, the value of log W/p is found. By inserting this and the values

TABLE 4 COEFFICIENTS FOR COMPUTING HEAT TRANSFER IN FLUES

(p/a = perimeter/area; B and m are coefficients)

p/a	B	m	p/a	B	m	p/a	B	m
0.50	8.867	0.494	2.00	9.053	0.296	6.20	9.350	0.194
0.51	8.868	0.491	2.10	9.062	0.291	6.40	9.362	0.192
0.52	8.870	0.487	2.20	9.071	0.286	6.60	9.373	0.190
0.53	8.872	0.483	2.30	9.080	0.281	6.80	9.384	0.188
0.54	8.874	0.480	2.40	9.089	0.277	7.00	9.394	0.186
0.55	8.876	0.477	2.50	9.098	0.273	7.20	9.404	0.184
0.56	8.878	0.474	2.60	9.108	0.269	7.40	9.414	0.183
0.57	8.880	0.471	2.70	9.116	0.265	7.60	9.423	0.181
0.58	8.881	0.467	2.80	9.124	0.261	7.80	9.433	0.179
0.59	8.883	0.464	2.90	9.132	0.258	8.00	9.444	0.177
0.60	8.884	0.461	3.00	9.140	0.255	8.20	9.455	0.176
0.65	8.892	0.449	3.20	9.154	0.249	8.40	9.465	0.174
0.70	8.900	0.437	3.40	9.170	0.242	8.60	9.474	0.172
0.75	8.908	0.426	3.60	9.185	0.237	8.80	9.484	0.170
0.80	8.915	0.416	3.70	9.199	0.233	9.00	9.494	0.169
0.85	8.922	0.406	4.00	9.213	0.229	9.20	9.504	0.168
0.90	8.929	0.390	4.20	9.227	0.225	9.40	9.513	0.166
1.00	8.942	0.383	4.40	9.241	0.221	9.60	9.522	0.165
1.10	8.955	0.370	4.60	9.254	0.217	9.80	9.532	0.164
1.20	8.968	0.358	4.80	9.266	0.214	10.00	9.542	0.163
1.30	8.980	0.347	5.00	9.278	0.211	10.20	9.550	0.162
1.40	8.991	0.337	5.20	9.290	0.208	10.40	9.557	0.161
1.50	9.002	0.329	5.40	9.303	0.205	10.50	9.553	0.160
1.60	9.013	0.322	5.60	9.315	0.203			
1.70	9.023	0.315	5.80	9.329	0.200			
1.80	9.034	0.308	6.00	9.338	0.197			
1.90	9.044	0.302						

[2] Trans. A.S.M.E., vol. 38, p. 407.

[3] Trans. A.S.M.E., vol. 39, p. 709; also, "A Study of the Locomotive Boiler," 1924, Simmons-Boardman Co.

of B and m in Equation [2], the value of the main coefficient M is found. Again, by inserting this in Equation [1] the temperature at any point along the length of the flue can be found. If the rate of flow of gas is changed, it is necessary to find the corresponding change in the value of log W/p, and to find from Equation [2] a new value of the main coefficient M. So long, however, as the dimensions of the flue remain unchanged the coefficients B and m remain the same.

The whole process of finding the drop in temperature along a flue may be summed up as follows: From the dimensions of the flue, its p/a ratio (that is, the ratio of perimeter to area) is found, and from Table 4 the corresponding values of the coefficients B and m are taken, either directly or by interpolation. These values and the value of W/p (that is, the weight of gas flowing per hour per inch of perimeter of the flue) are used in Equation [2] to find the value of its main coefficient M. Having this and knowing t, the temperature of the flue wall, and T_1, the gas temperature at a point along the flue, Equation [1] enables one to find the gas temperature T_2 at any desired distance, say x feet further along the flue.

When the equations are applied in practice, it will be found that the relation between the coefficients B and m derived from the perimeter-area ratio is such that if the rate of gas flow remains constant, an increase in the p/a ratio increases the rate at which heat is transferred. Also, if the p/a ratio remains constant, an increase in the rate of gas flow tends to reduce the temperature drop over a given length of the flue. It will be found, however, that the reduction in temperature drop is less in proportion than the increase in the rate of flow of the gas. That is, at the increased rate of flow the flue takes less out of each pound of gas, but the increase in the number of pounds of gas is proportionately greater, so that the total amount of gas taken up by the flue is increased.

TABLE 5 DIMENSIONS OF LOCOMOTIVES

Locomotive, Class	K2sa	M1s
Locomotive, No.	877	4700
Evaporative flues, outside diameter, in.	2 1/4	2 1/4
Evaporative flues, number	202	114
Evaporative flues, inside diameter, in.	2.000	1.982
Perimeter in contact with gas, in.	6.28	6.24
Area inside, sq. in.	3.14	3.08
Length, ft.	20.8	19.0
Superheater flues, outside diameter, in.	5 1/2	3 1/4
Superheater flues, number	32	200
Superheater flues, inside diameter, in.	5.25	2.982
Perimeter in contact with gas, in.	16.49	9.39
Area, sq. in.	21.65	6.98
Length, ft.	20.8	19.0
Superheater pipes, outside diameter, in.	1 7/16	1 1/8
Superheater pipes, number in each flue	4	2
Perimeter in contact with gas in each flue, in.	18.06	7.08
Area taken up of all pipes in each flue, sq. in.	6.49	1.99
Length, ft.	18.8	18.167

TABLE 6 EXPERIMENTAL DATA FROM SMOOTH CURVES

Locomotive, Class	K2sa	M1s	M1s
Locomotive, No.	877	4700	4700
Evaporation, lb. of steam per hour	50,000	65,000	35,000
Total weight of gases of combustion per hour	97,500	102,900	56,000
Temperature of gases at back flue sheet, deg. fahr.	2,080	2,000	1,200
Temperature of gases in smoke box, deg. fahr.	620	570	510
Steam pressure, lb. per sq. in.	205	250	250
Steam temperature in boiler, deg. fahr.	390	406	406
Steam temperature in branch pipe, deg. fahr.	670	630	560
Feedwater temperature, deg. fahr.	50	65	65
Heat per pound of steam:			
Heat to produce saturated steam	1,182	1,169	1,169
Heat required for superheating	150	126	90
Heat to produce superheated steam from feedwater	1,332	1,295	1,259
Superheat as per cent of total heat for production of steam	11.2	9.8	7.1

Methods of Calculation

Having described in general terms the results obtained, consideration is now given to the calculations involved in applying the Fry method to specific conditions. For present purposes two different locomotives are considered. Both belong to the Pennsylvania Railroad and have been tested on the locomotive testing plant at Altoona. Information regarding the results of these tests given to the author by Mr. J. T. Wallis, assistant vice-president, is the source of the experimental data used in the calculations. The dimensions of the locomotives pertinent to the present purpose are collected in Table 5, while the necessary experimental data are given in Table 6. These data are taken from smooth curves drawn for a complete series of tests for each locomotive. In this way the effect of irregularities in individual tests is eliminated. The two locomotives dealt with are a 4–6–2 Pacific type, Class K4s, No. 877, fitted with a type A superheater, and a 4–8–2 Mountain type, Class M1s, No. 4700, with a type E superheater. Locomotive No. 877 is studied when evaporating 50,000 lb. of water per hour, which represents a high rate of operation, while locomotive No. 4700 is taken at both high and low rates, the evaporation in the two cases being, respectively, 65,000 and 35,000 lb. of water per hour.

TABLE 7 DIMENSIONS OF FLUES WITH HEAT-TRANSFER COEFFICIENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Locomotive	Flues	Flues: Diameter Outside, in.	Flues: Diameter Inside, in.	Flues: Perimeter, in.	Flues: Area, sq. in.	Superheater pipes: Number in each flue	Superheater pipes: Outside diameter, in.	Superheater pipes: Total perimeter, in.	Superheater pipes: Total area, sq. in.	Total perimeter of flues and pipes P, in.	Net area for passage of gas a, sq. in.	Ratio p/a	Flue coefficients from Table 4 B	Flue coefficients from Table 4 m
K2sa No. 877	2 1/4-in. evaporative	2.25	2.00	6.283	3.142	..	....	....	....	6.283	3.142	2.000	9.053	0.296
	5 1/2-in. flues:													
	(a) Without superheater pipes	5.50	5.25	16.493	21.648		....	....	....	16.493	21.648	0.760	8.909	0.424
	With pipes in place:													
	(b) Evaporative surface only	5.50	5.25	16.493	21.648	4	1 7/16	18.064	6.492	16.493	15.156	1.088	8.953	0.372
	(c) Superheater surface only	5.50	5.25	16.493	21.648	4	1 7/16	18.064	6.492	16.493	15.156	1.200	8.968	0.358
	(d) Evaporative and superheater combined	5.50	5.25	16.493	21.648	4	1 7/16	18.064	6.492	34.557	15.156	2.280	9.078	0.282
M1s No. 4700	2 1/4-in. evaporative	2.25	1.982	6.22	3.075	..	....	....	....	6.227	3.084	2.020	9.055	0.295
	3 1/4-in. flues:													
	(a) Without superheater pipes	3.25	2.982	9.39	6.98	..	....	....	....	9.404	6.984	1.345	8.984	0.343
	With pipes in place:													
	(b) Evaporative surface only	3.25	2.982	9.39	6.98	2	1.125	7.08	1.99	9.484	4.996	1.880	9.042	0.301
	(c) Superheater surface only	3.25	2.982	9.39	6.98	2	1.125	7.08	1.99	7.068	4.996	1.420	8.992	0.336
	(d) Evaporative and superheater combined	3.25	2.982	9.39	6.98	2	1.125	7.08	1.99	16.552	4.996	3.30	9.163	0.246

Dimensional Coefficients for Flues

In order to deal with heat transfer in the flues it is necessary to obtain values for the coefficients of Equations [1] and [2]. The coefficients B and m used in Equation [2] depend only on the dimensions of the flues. The dimensions required are set out in Table 6. Using these dimensions, the coefficients can be obtained from Table 4. With the evaporative flues this is a very simple matter. The area divided into the inside perimeter gives the p/a ratio, and the values of B and m can then be taken from Table 4, either directly or by interpolation.

Thus for locomotive No. 877 the first line in column 13, Table

7, shows that the $2^1/_2$-in. evaporative flues have a p/a ratio of 2.00, and for this value of p/a Table 4 gives $B = 9.053$ and $m = 0.296$. For the flues which carry the superheater pipes four sets of coefficients are needed, one for the back end before the superheater pipes are reached and three sets so that the heat transfer may be dealt with for the evaporative and the superheater surfaces separately and also for the combined surfaces.

The method followed is shown in Table 7. Taking locomotive No. 877 as an example:

(*a*) Before the superheater pipes are reached, there is, neglecting the swaging at the flue sheet, a plain flue of $5^1/_2$-in. inside diameter for which the p/a ratio is 0.760. The corresponding values for B and m taken from Table 4 are set down in columns 14 and 15.

Flow of Gas in Flues—Temperature of Flue Wall

In order to use the dimensional coefficients B and m in Equation [2], it is necessary to know the rate at which the gas flows through the various flues. The experimental data show the total amount of gas passing per hour through the boiler for a given rate of operation, but there is no direct experimental evidence as to the distribution of this gas between the evaporative and superheater flues. This distribution is estimated for the present purposes by a method which appears to be justified by the results it gives. It is assumed that the gas carried by each of the two groups of flues is proportional to the total area of the group and is inversely proportional to the p/a ratio of the group. The latter half of this assumption implies that the resistance of the flues to the flow of gas is inversely proportional to the p/a ratio. Until definite experimental information is available, this approximate method for distributing the gas between the two groups of flues seems to be satisfactory. Computation of the gas distribution can be followed in columns 5 to 10 of Table 8. Column 7 gives the total area of each group of flues, and column 8 the resistance factor which is the reciprocal of the p/a ratio. The product of these two columns gives the relative gas-carrying capacity of each group. This is expressed as a percentage in column 10, and these percentages of the total rate give the amount of gas carried by each group. Table 9 continues the computation, showing the weight of gas in each flue, column 4, and the weight of gas per inch of perimeter per hour, W/p, column 5. With this figure and the coefficients B and m, Equation [2] is used to find the values of the main coefficient M, column 9.

To complete the data necessary for the use of Equation [1] to determine the temperature drop along the flue, information is needed as to the mean temperature of the flue wall in contact with the gas. This must be estimated from the known tem-

TABLE 8 GAS DISTRIBUTION IN FLUES

1	2	3	4	5	6	7	8	9	10	11	12
Locomotive	Rate of evaporation, lb. per hr.	Total weight of gas, lb. per hr.	Flues, diameter, in.	Number of flues	Area of each flue, a, sq. in.	Total area of each group flues, A, sq. in.	Resistance factor a/p	Gas-carrying capacity of each group: Relative $A \times a/p$	Gas-carrying capacity of each group: As per cent	Weight of gas per hour: In each group	Weight of gas per hour: Per flue, W
K2sa			$2^1/_4$	202	3.142	635	0.500	317	59.8	58,250	288
No. 877	50,000	97,400	$5^1/_2$	32	15.16	485	0.448	213	40.2	39,150	1224
			Total	...	..	1120	...	530	100.0	97,400	...
M1s			$2^1/_4$	114	3.08	351	0.495	173.5	36.5	37,500	329
No. 4700	65,000	102,900	$3^1/_4$	200	4.99	998	0.303	302	63.5	65,400	327
			Total	...	..	1349	...	475.5	100.0	102,900	..
M1s			$2^1/_4$	114	3.08	351	0.495	173.5	36.5	20,400	179
No. 4700	35,000	56,000	$3^1/_4$	200	4.99	998	0.303	302	63.5	35,600	178
			Total	...	..	1349	...	475.5	100.0	56,000	..

TABLE 9 FINAL HEAT-TRANSFER COEFFICIENTS

Locomotive	Rate of evaporation, lb. per hr.	Flues	Weight of gas per hour in each flue, W, lb. per hr.	Perimeter, P, in.	Weight of gas per hour per inch of perimeter, W/p, lb. per in.	Flue coefficients B	Flue coefficients m	Main coefficient from columns 6, 7, 8 and Equation [2] M
1	2	3	4	5	6	7	8	9
		$2^1/_4$-in. evaporative flues	288	6.283	45.9	9.053	0.296	0.0364
		$5^1/_2$-in. flues	1244					
		(*a*) Without superheater pipes	1244	16.493	74.2	8.909	0.424	0.0131
K2sa	50,000	With superheater pipes:						
No. 877		(*b*) Evaporative surface only	1244	16.493	74.2	8.953	0.372	0.0181
		(*c*) Superheater surface only	1244	18.064	67.8	8.968	0.358	0.0206
		(*d*) Evap. & suph. surface combined	1244	34.557	35.4	9.078	0.282	0.0438
		$2^1/_4$-in. evaporative flues	329	6.227	53.0	9.055	0.295	0.0352
		$3^1/_4$-in. flues	327					
		(*a*) Without superheater pipes	327	9.484	34.5	8.984	0.343	0.0285
M1s	65,000	With superheater pipes:						
No. 4700		(*b*) Evaporative surface only	327	9.484	34.5	9.042	0.301	0.0376
		(*c*) Superheater surface only	327	7.068	46.3	8.992	0.336	0.0271
		(*d*) Evap. & suph. surface combined	327	16.552	19.75	9.163	0.246	0.0698
		$2^1/_4$-in. evaporative flues	179	6.227	28.8	9.055	0.295	0.0417
		$3^1/_4$-in. flues	178					
		(*a*) Without superheater pipes	178	9.484	18.8	8.984	0.343	0.0352
M1s	35,000	With superheater pipes:						
No. 4700		(*b*) Evaporative surface only	178	9.484	18.8	9.042	0.301	0.0456
		(*c*) Superheater surface only	178	7.068	25.2	8.992	0.336	0.0332
		(*d*) Evap. & suph. surface combined	178	16.552	10.76	9.163	0.246	0.0813

When the superheater pipes are reached they reduce the fire area available for the passage of the gases, so that the net area becomes 15.156 sq. in. instead of 21.648 sq. in. The gases passing through this area may be considered as giving up heat in one of three ways:

(*b*) By transfer to the evaporative surface of the outer flue only. The receiving perimeter in this case is 16.493 in. and the p/a ratio 1.088

(*c*) By transfer to the surface of the superheater pipes only. In this case the receiving perimeter is 18.064 in. and the p/a ratio is 1.200.

(*d*) By transfer to the evaporative and superheater surfaces simultaneously. In this case the combined receiving perimeter is 34.557 in. and the p/a ratio is 2.280.

The values of the coefficients B and m taken from Table 4 for all three values of p/a are tabulated in columns 14 and 15 of Table 7.

perature of the water and steam with which the transmitting surface of the flue is in contact. The evaporative flues receive

TABLE 10 TEMPERATURES OF RECEIVING AND TRANSMITTING SURFACES OF FLUES

Locomotive, Class	K2sa	M1s	M1s
Locomotive, No.	877	4700	4700
Rate of evaporation in pounds of steam per hour, lb.	50,000	65,000	35,000
(*A*) Temperature of saturated steam, deg. fahr.	390	406	406
(*B*) Temp. of steam in branch pipe, deg. fahr.	670	630	560
(*C*) Mean temperature of steam in superheater pipes (*C*) is average of (*A*) and (*B*)	530	518	483
(*D*) Mean temperature of combined superheater and evaporative surfaces (transmission side) for flues with superheater pipes (*D*) is average of (*A*) and (*C*)	460	462	444
Heat per inch of total perimeter per hour carried by gas leaving firebox, B.t.u.	22,600	13,500	4,200
Temperature differential to be added to transmitting surface temperature to give mean receiving wall temp. for full flue length, deg. fahr.	45	25	10

heat from the gases on their inside surface and transmit it through their outside surface to water at a temperature corresponding to the boiler pressure, while the superheater pipes receive heat on their outside surface and transmit it from their inside surface to steam which has a temperature ranging from that of the saturated steam up to the temperature observed in the branch pipe. The temperature gradient due to the heat flow through the flue wall establishes a temperature differential between the transmitting and receiving surfaces. This differential will be greater the greater the rate of heat received and transmitted through the flue wall. It will therefore be greater at the firebox end than it is at the smokebox end of the flue, and at any given point in the flue will be greater for a high rate of evaporation than for a low. It has been found that for calculations of the temperature drop over the full length of the flues of a locomotive boiler, satisfactory results are obtained if the mean receiving flue-wall temperature is taken to differ from the transmitting-wall temperature by the differential indicated in Fig. 1, where the differential is made to vary with the heat carried into the flues measured in B.t.u. per hour per inch of total perimeter. The heat in the gases entering the flues is found from the total weight of gas, the temperatures, and the heat content for that temperature as given in Table 10. This is divided by the total perimeter of the flues, including evaporative and superheater surface. The values in Fig. 1 have been arrived at by computing smokebox temperatures from test data and comparing the results with the observed smokebox temperatures. No information is available which would enable the differential to be determined separately for the evaporative and superheater surfaces. In the absence of more complete and better-established information, the curve of Fig. 1 is put forward as a reasonably accurate basis for calculation.[4]

[4] The author is indebted to Mr. Robert Rennie for suggesting the use of a differential of this sort.

Table 11 shows the flue-wall temperatures which have been used in the three series of computations covered by the present paper. It will be seen that for dealing with short flue sections the differential is given a high value for sections near the firebox and a low value for sections near the flue sheet. The temperature of the transmitting surface of the flue is assumed to be that of the saturated steam for the evaporative surfaces. For the superheater surfaces the transmitting-surface temperature is taken to be the mean between that of the saturated steam and that of the steam in the branch pipe. When the evaporative and superheater surfaces of the superheater are combined in a single calculation, this mean steam temperature is averaged with the saturated steam temperature.

Determination of Temperature Drop Along Flues

The foregoing calculations and considerations provide all the elements necessary for the application of Equation [1] to compute the temperature drop along the flues for any operating condition. Take, for example, Locomotive No. 877 evaporating 50,000 lb. of water per hour, and consider first the $2^1/_4$-in.

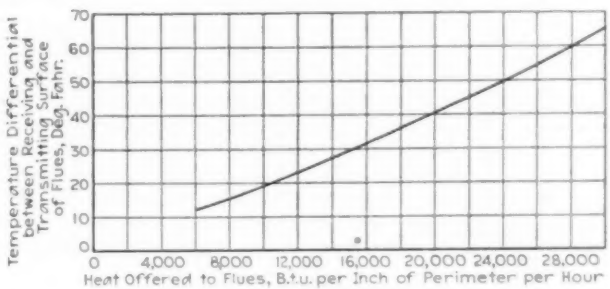


Fig. 1 Assumed Temperature Differential for Full-Length Flues

evaporative flues. Having values for T_1, t, M, and x, it is required to find T_2 from the equation

$$\text{lolog } T_1/t - Mx = \text{lolog } T_2/t \quad \ldots\ldots\ldots\ldots [1]$$

The sequence of calculations shown on the work sheet, Table 13, shows a simple and direct method of procedure. First is set down log T_1, the logarithm of the absolute temperature at which the gases enter the flue. Below this is log t, the logarithm of the absolute temperature of the receiving flue wall. The difference gives log T_1/t, and the logarithm of this is lolog T_1/t. Alongside of this is the value of the main coefficient M which has been determined previously and set down in Table 9. This coefficient is multiplied by the length of the flue over which the temperature drop is to be computed; in the present case, the

TABLE 11 MEAN TEMPERATURE OF HEAT-RECEIVING SURFACE OF FLUES

	Locomotive K2sa, No. 877, 50,000 lb. of steam per hour				Locomotive M1s, No. 4700, 65,000 lb. of steam per hour			
Flue section distance from back flue sheet	Differential[1] between transmitting and receiving flue-wall temperature, deg. fahr.	Mean temperature of receiving surface of flue wall: Evaporative surface, deg. fahr.	Superheater surface, deg. fahr.	Combined evaporative and superheater surfaces, deg. fahr.	Differential between transmitting and receiving flue-wall temperature, deg. fahr.	Mean temperature of receiving surface of flue wall: Evaporative surface, deg. fahr.	Superheater surface, deg. fahr.	Combined evaporative and superheater surfaces, deg. fahr.
0 to 1 ft.	100	490	630	560	75	481	593	537
1 ft. to 2 ft.	100	490	630	560	75	481	593	537
2 ft. to 3 ft.	80	470	610	540	65	471	583	527
3 ft. to 4 ft.	70	460	600	530	55	461	573	517
4 ft. to 5 ft.	65	455	595	525	50	456	568	512
5 ft. to 7 ft.	60	450	590	520	45	451	563	507
7 ft. to 9 ft.	55	445	585	515	40	446	558	502
9 ft. to 11 ft.	50	440	580	510	35	441	553	497
11 ft. to 13 ft.	45	435	575	505	30	436	548	492
13 ft. to 15 ft.	40	430	570	500	25	431	543	487
15 ft. to 18 ft.	35	425	565	495	20	426	538	482
18 ft. to 21 ft.	30	420	560	490	15	421	533	477

[1] This "differential" is the figure to be added to the temperature of the receiving surface to find the flue-wall temperature to be used in Equation [1].

whole length of the flue or 20.8 ft. This product Mx deducted from lolog T_1/t gives according to Equation [1] the value of lolog T_2/t. By finding the antilog of this (that is to say, the number of which it is the log) log T_2/t is obtained. The addition of log t gives log T_2, from which T_2, the end temperature in absolute units, is found.

For the superheater flues a similar calculation is carried out, but in two steps. The first deals with the back 2 ft. of the $5^1/_2$-in. flue which does not contain any superheater pipes. For this portion of the calculation the main coefficient M has the value given under (a) in Table 7. For the remainder of the flues the gas is taken to lose heat to the evaporative surface of the $5^1/_2$-in. being used for the evaporative surface and the (c) value for the superheater pipes. Equation [1] is applied just as before, except that the calculation must, for reasons which follow, be restricted to short sections of the flue length. Consider, for example, the section of superheater flue lying between 2 and 3 ft. measured from the back flue sheet. This is the first foot of flue containing the superheater pipes. The temperature of the gases entering this section is, as shown in Table 2, 1938 deg. fahr. Now if the temperature drop be computed for heat transfer to the *evaporative* surface only, the temperature at the 3-ft. point will be found to be 1840 deg. fahr., a temperature drop which will be seen from Table 12 to correspond to a transfer of 30 B.t.u. from each pound of gas. Computed for heat transfer to the *superheater* surface only, the temperature at the 3-ft. point will be found to be 1845 deg. fahr., corresponding to a loss of 27 B.t.u. per pound of gas. Now if the heat transfers to evaporative and to superheater surfaces, which have been computed as though acting separately, are assumed to take at the same time, the gas, which has a temperature of 1938 deg. fahr. at the 2-ft. point, would lose 30 + 27 = 57 B.t.u. by the 3-ft. point. This from Table 12 would give a temperature of 1745 deg. fahr. at the 3-ft. point, which is the same temperature as would be found for this point by computing the temperature drop for the combined evaporative and superheating surfaces. The same thing is found for other short lengths of the flues. It is therefore concluded that by dividing the flue into short sections, in which the temperature drop is not great compared with the initial temperature, the method of calculation can be used to find the amount of heat taken up by the superheater. In doing this, though, the initial temperature for each section must be that found by computing the heat transfer to the combined superheater and evaporative surfaces. Thus, in Table 2, column 2 shows the temperature drop along the flue computed for heat transfer to both superheater and evaporative surfaces—that is, with the coefficient M having the value given under (d) in Table 9. Then if for each of the sections the temperature of column 2 is taken as the initial gas temperature and the value of M given under (b) in Table 9 is used to compute the heat transfer, the values given in column 5 of Table 2 are obtained for the heat given up per pound of gas in each section. By summing the heat given up in the successive sections and expressing this in terms of the heat in the total weight of gas passing through all flues, the figures in Table 3 are obtained. These show that the computed heat transfer to the superheater agrees quite closely with the amount of superheat as measured in the experiments.

TABLE 12 SENSIBLE HEAT IN GASES OF COMBUSTION IN B.T.U. PER POUND OF GAS AT VARIOUS TEMPERATURES

	0°	400°	500°	600°	700°	800°	900°	1000°	1100°
0°.....	0	96	121	146	171	197	223	249	275
5°.....	1	97	122	147	172	198	224	250	276
10°.....	2	98	123	148	173	199	225	251	277
15°.....	3	99	124	149	175	201	226	252	278
20°.....	4	101	126	151	176	202	228	254	280
25°.....	5	102	127	152	177	203	229	255	281
30°.....	7	103	128	153	178	204	230	256	282
35°.....	8	104	129	154	180	206	231	257	284
40°.....	9	106	131	156	181	207	233	259	285
45°.....	10	107	132	157	182	208	234	260	286
50°.....	12	108	133	158	183	209	235	261	288
55°.....	13	109	134	159	185	211	236	262	289
60°.....	14	111	136	161	186	212	238	264	290
65°.....	15	112	137	162	187	213	239	265	292
70°.....	17	113	138	163	189	215	240	266	293
75°.....	18	114	139	164	190	216	242	268	295
80°.....	19	116	141	166	191	217	243	269	296
85°.....	20	117	142	167	192	218	245	270	297
90°.....	21	118	143	168	194	220	246	272	299
95°.....	22	119	144	169	195	221	247	273	300
100°.....	24	121	146	171	197	223	249	275	302

	1200°	1400°	1600°	1800°	2000°	2200°	2400°	2600°
0°.....	302	355	412	468	526	585	645	706
10°.....	305	358	415	471	529	588	648	709
20°.....	307	361	417	474	532	591	651	712
30°.....	310	363	420	477	535	594	654	715
40°.....	313	366	423	480	538	597	657	718
50°.....	315	369	426	482	540	600	660	721
60°.....	318	371	429	485	543	603	663	724
70°.....	321	374	431	488	546	606	666	727
80°.....	323	377	434	491	549	609	669	730
90°.....	326	380	437	494	552	612	672	733

	1300°	1500°	1700°	1900°	2100°	2300°	2500°	2700°
0°.....	329	383	440	497	555	615	675	737
10°.....	332	386	443	500	558	618	678	740
20°.....	335	389	445	503	561	621	681	743
30°.....	337	392	448	506	564	624	684	746
40°.....	340	395	451	509	567	627	687	749
50°.....	342	397	454	512	570	570	690	752
60°.....	345	400	457	514	573	633	693	755
70°.....	247	403	459	517	576	636	696	758
80°.....	350	406	462	520	579	639	699	761
90°.....	352	409	465	523	582	642	702	764
100°.....	355	412	468	625	585	645	706	768

The table is computed from the values of the mean specific heat given by the equation $Cp = 0.235 + 0.000014\ t$ where t is the gas temperature in deg. fahr.

This does not include the latent heat of the water vapor.

TABLE 13 WORK SHEET

(Locomotive No. 877 at an evaporation of 50,000 lb. of water per hour, $2^1/_4$-in. flues, temperature drop firebox to smokebox)

Temperature at back flue sheet,	2080° F.	T_1 = 2540° absolute
Temperature of water surface of flues	388° F.	
Differential (Table 10),	45° F.	
	433° F.	t = 893° absolute
log T_1 = log 2540	= 3.405	M = 0.0363 (Table 9)
log t = log 893	= 2.954	x = 20.8 flue length
log T_1/t	= 0.454	Mx = 0.755
lolog T_1/t = log 0.454	= 9.657	
Mx	= 0.755	
lolog T_2/t = lolog T_1/t − Mx	= 8.902	
log T_2/t = antilog 8.902	= 0.080	
log t	2.951	
log T_2	3.031	
T_2	= 1074 deg. absolute	
	460	
Temperature at front flue sheet	= 614 deg. fahr.	

and to the superheater pipes simultaneously, and the coefficient M has the value given under (d) in Table 9.

When carried out, these calculations show that at the front flue sheet the gas comes out of the $2^1/_4$-in. evaporative flues at 614 deg. fahr., and out of the $5^1/_2$-in. superheater flues at 643 deg. fahr. To find the corresponding average smokebox temperature it is necessary to take into account the weight of gas from each set of flues, column 11, Table 8, and the specific heat of the gases, Table 12. As shown in Table 1, the average smokebox temperature thus computed is 625 deg. fahr., while the observed temperature corresponding to the same conditions was 620 deg. fahr. This agreement is very satisfactory.

In addition to computing the total drop of temperature from back flue sheet to front flue sheet, the method can be used to compute the drop from foot to foot along the flues, and also to determine for the superheater flues the amount of heat taken up by the evaporative surface and the amount taken up by the superheater pipes. For this latter purpose the coefficient M has the values given under (b) and (c) in Table 9, the (b) value

Discussion

H. B. OATLEY.[5] The paper is of keen interest to all those who are engaged in the design and construction of locomotive boilers. The great heat-absorbing capacity of the flue and the superheater pipe used therewith is an object continuously striven for in designing. The conditions attending locomotive development have made necessary a more intensive study of this matter. Among the causes which have made this subject of ever greater importance are:

(1) Increasing demand for boiler output
(2) Demand for still higher steam temperatures
(3) A decrease in the percentage of the total heat liberated from the fuel available for use in the fire-tube type of superheater
(4) An increased duty on the superheater as a result of a larger moisture content in the steam to be superheated
(5) Increasing steam pressures.

The type E superheater, with which engine No. 4700 was fitted, has come into widespread use as a means of meeting the conditions itemized. It has been necessary to provide greater superheating capacity within limits of boiler diameter and length, which cannot be increased to any great extent due naturally to the limitations of height, width, and weight, within which the locomotive can be built. It is naturally gratifying to find that in applying the theory and formulas which the author has developed, the proportions of flue and superheater unit used in the type E superheater show a greater heat-absorbing capacity and a noticeably lower gas-exit temperature than with the type A superheater.

These conditions have been pronounced during the past ten or fifteen years and have brought about changes in superheater proportion which are used in the paper. The problem of modifying the superheater design to keep pace with the trend of locomotive development is assisted by such studies as the author has made.

It may, however, not be out of place to point out some of the difficulties which are encountered when we come to apply theory to practice. These conditions, resulting from the changes in locomotive requirements enumerated, are of course well known to students of this problem. To follow the theoretically correct values determined on a heat-absorption basis may bring practical difficulties of a magnitude which will offset the theoretical advantages. In this, as in most other problems, a compromise to get the best all-around results must be made.

We know, and calculations using the formula set forth in the paper confirm, that a larger value for p/a will give greater heat absorption. Increasing p or decreasing a will have this result, but other factors must be taken into account.

For example, if the flue diameter is increased, p/a is thus decreased, the total number of flues in a given sized boiler will be decreased, the total amount of evaporating surface in the boiler decreased, the total steam area through the superheater decreased, and the smokebox temperature increased, thus causing some decrease in boiler efficiency which the higher degree of superheat and the increased cylinder efficiency resulting therefrom may not cancel. From the practical side it must be considered that, so long as fire tubes are used and boiler pressures continue to increase, an increase in the tube diameter means a thicker tube wall, entailing greater attention to and possibly trouble in tube setting.

If we now increase the diameter of the superheater pipe, we will decrease a and at the same time increase p; the ratio p/a changing also. The effect here is to increase superheating surface, but to decrease the total gas area through a given size of boiler; hence, an increase in the draft requirement for any given quantity of gas and a decrease in the mean effective pressure in the cylinders as a result of the higher back pressure needed for the greater draft required. We also increase the total steam area through the superheater and decrease the steam velocity through the units. While this increased steam area is advantageous from the standpoint of smaller pressure drop through the superheater, it does not so well contribute to a lower metal temperature in the superheater units subjected to the higher gas temperatures and therefore must be regarded as less desirable.

Reference has been made in the paper to the fact that the gas temperatures through the last 7 ft. of the flues is not high enough to impart additional heat to the steam in the outgoing pipe. That statement is true for the type E equipped engine at the rate of 65,000 lb. per hour. It is quite probable that this distance varies with the rating, and perhaps through a considerable range. It must not be forgotten, however, that there is heat imparted to the steam in the ingoing pipe and, furthermore, that the temperature head for heat to flow from the superheater pipe is relatively small throughout the distance stated. The conditions, however, with the type E superheater do point to the fact that tube lengths may easily be unduly great if we solely consider flue-gas temperatures. On the other hand, it must not be forgotten that the demand for great boiler-evaporation capacity necessitates full advantage being taken of all the available length.

These illustrations are given merely to indicate some of the problems involved in what may at first appear to be changes in unimportant details. They do show, however, that the locomotive and its details compose the "linked triangle of fire, water, and air" which the author has used so appropriately in his book on the locomotive boiler.

They show, it is believed, that it is almost impossible to modify one part without, adversely or otherwise, affecting the performance of other portions, and hence the performance of the locomotive as a whole.

C. W. BENICA.[6] The author has proposed a method of calculating the superheat temperature from the amount of heat absorbed by the steam in passing through the superheater pipes. This paper, in connection with the author's paper delivered before the Society in 1917, the summary of an article in *Mechanical Engineering* for November, 1920, and his book entitled, "A Study of the Locomotive Boiler," provides the designer with the necessary data for connecting test-plant results to anticipated performance. The author deals mostly with known values for the gas analysis, combustion conditions, temperatures in the firebox and smokebox, and the necessary data covering the extent of actual heating surfaces, etc., of an existing locomotive.

In order to obtain the temperature drop through the flues the author again uses his log-log equation, starting with a known value for the gas temperature t_1 at the tube entrance. The superheater designer, however, does not have this very important figure; and a survey of much of the printed matter extant and of the great variation in tube- and flue-temperature-drop curves that have been given to us through the publication of papers and test reports by C. A. Brandt, C. A. Seley, J. T. Anthony, the Pennsylvania Railroad locomotive builders, and the foreign technical press, as well as by the author himself, shows that this temperature must be calculated or assumed only after a careful analysis has been made of firebox radiation and the combustion conditions before the gases enter the tubes. Since the value of t_1 is the starting point and in a way determines what can be expected from the tube and flue section of the boiler, the writer has assembled the foregoing data and has worked out a formula that,

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while it is to a large extent empirical, seems to fit the data very well.

The firebox temperature, as measured, follows closely the formula $t_1 = a + b\sqrt{G}$ where t_1 = temperature in firebox in deg. fahr., G = combustion rate in pounds of coal fired per square foot of grate area per hour, and where a = 1660 and 1100 and b = 70 and 120 for passenger and freight locomotives, respectively. These constants seem wide apart, but they are characteristic for locomotives in the two respective classes of service, and even though wide apart, they give a comparatively close agreement with the test data. At a combustion rate of about 125 lb. of coal per square foot of grate area, the formulas give equal temperatures for freight and passenger locomotives. Values for t_1, firebox temperature, and t_2, temperature at tube entrance, must not be confused.

Two variables enter into the calculation of firebox temperature not considered in the foregoing, but which are important to the superheater designer—air supply and the ratio of firebox volume to firebox heating surface. The author usually deals with test data from which the firebox gas composition and air supply can be determined, but the designer, not having this data, must take an average figure for weight of gases per pounds of coal burned at about 16.3 to 0.032 G. One must however, consider the fact that the ratio of coal burned to coal fired depends considerably on the particular firebox or boiler design, but is approximately represented by $1.00 - aG^2$ where a = 0.000020 and 0.000016 for freight and passenger locomotives, respectively. Combined with the t_1 formula, we get $t_1 = 2000 + 60\sqrt{G} - 16.7\,(16.3 - 0.032\,G)$ approximately.

The other variable, ratio of firebox volume to heating surface, seems to be more regular in its effect on firebox temperature because these dimensions are directly involved in extracting the heat in the firebox, reducing its temperature in some ratio to their extent. Tests of twenty locomotives where this ratio varied from 0.75 to 1.50 showed remarkable adherence to the formula $t_1 = (2400 - 533\ R) + 75\ \sqrt{G}$, where R = firebox volume ÷ firebox heating surface, the extent of these dimensions being capable of accurate estimation from the designer's drawings.

The temperature of the firebox at the tube sheet bears a direct relation to the temperature of the firebox in all data investigated except in one series of tests where the relation was inverse; viz., a higher firebox temperature occurred with an increase in combustion rate, but the relation of tube-entrance temperature to firebox temperature decreased with an increased combustion rate. The reduction of the gas temperature at the tube sheet has been compared to the reduction in temperature just above a gauze placed over a bunsen burner where the conductivity of the gauze reduces the temperature above it to a point where the gases do not burn in a flame; the evaporation in pounds of water per square foot of surface per hour is probably greater at the back tube sheet than anywhere else in the boiler because the temperature drop and gas flow are greatest at this location.

Due to the discrepancies usually found in collecting and arranging considerable data from various sources it was found that the most regular results would be obtained by representing the various temperature drops as a percentage of the firebox temperature, where the firebox temperature = 1.0. Thus, the temperature at the tube entrance, the quantity T_1 of the paper, is found to be $t_2 = ct_1$ where $c = 0.654 + 0.00143\ G$ for 2 in. or $2^1/_4$ in. tubes, $c = 0.600 + 0.00176\ G$ for $5^1/_2$-in. flues, and t_1 = the firebox temperature as estimated by one of the three formulas given. Having this value for t_2, the calculation can progress according to the author's method, using the log-log Formulas [1] and [2]. The writer has found that fairly reliable results for design or estimates for the temperature drop through the tubes and flues can be represented by the equation $t_x = t_1\,(1.00 + KL)$, where C is the value of C as already determined and k = 0.110 for 2 in. and $2^1/_4$-in. tubes and 0.0980 for $5^1/_2$-in. flues, L being the length of the tube or flue up to the point where t_x is to be determined. It is not expected that this formula is to be taken in place of the author's more accurate and scientific expression, but in the absence of coal and gas analysis, of quantity of gases per square inch of tube and flue perimeters, and of the important relation of coal burned to coal fired, the foregoing expression fairly well represents test data in as simple a form as can be expected over ordinary ranges.

It has been found that the degree of superheat obtained in a type A superheater can be fairly well represented by $S^\circ = K_1\sqrt{E}$, where K_1 = 6.25 and 6.00 for passenger and freight locomotives, respectively, and E = equivalent evaporation in pounds per hour per square inch of pipe cross-sectional area. (One pipe is considered to each flue and must not be confused with four passes going to make up one pipe.) This simple expression does not give accurate results for the half-return bend, extra length, or short superheater. It must not be overlooked that the difference in specific heat of superheated steam is 13 times as great from saturated steam to 100 deg. superheat as it is from 200 deg. to 300 deg. superheat and that the superheater acts as a steam drier through a fraction of its surface. It has often occurred to the writer that the superheater design and heat transfer data should start at the smokebox end where the temperature of the saturated steam and combustion gases vary through a much smaller range than close to the rear tube sheet.

Mr. Oatley's discussion of the paper stresses the difficulties of designing a superheater to get the desired results within space limitations and physical specifications. The average weight of 30 type A superheaters was determined to be 9.3 lb. per sq. ft. of superheater heating surface. The practical difficulty in designing modern locomotive boilers and superheaters and providing for sufficient transfer of heat through their surfaces is closely wrapped up with the limitations of weight that can be given to the various heating surfaces. The weight analysis of a larger number of locomotive boilers shows that there is a very small difference in the ratio of boiler weight to total locomotive weight; viz., if we let W_L = approximate estimated total weight of a proposed locomotive and W_b = weight of the bare boiler, shell, tubes, and firebox, including water, then $W_b = wW_L$, where w = 0.341, 0.342, and 0.337 for passenger, freight, and Mallet locomotives, respectively. The variation in w is small, the maximum and minimum values for 35 standard-gage locomotives being 0.321 and 0.368 over a range in locomotive weights from a 200,000-lb. Atlantic type to a 680,000-lb. Mallet type. The relation existing between the weight and extent of the boiler heating surfaces is represented by the equation $W_b = 22.0\ A_t + 167\ A_f - C$, where A_f is the firebox heating surface (syphons, arches, etc. excluded), A_t = tube plus flue heating surface, and C = a constant and equals $18{,}500 + 2.5\ (A_t + A_f)$. For ordinary ratios of tube and flue heating surface to firebox heating surface the weight of the boiler can be taken to be $W_b = 32.5\ (A_t + A_f) - 18{,}500$.

It would be a valuable contribution to the Society and to the railroad engineering fraternity in general if the author would give a few rules or formulas connecting his heat-balance theory to the proportioning of heating surfaces and cylinder performance. If the heat-unit basis of design could be established for preparing designs and proportioning locomotives along the conventional lines of the present machine, it would not be so difficult to introduce such locomotives as have been described in Mr. Stuebing's paper and whose appearance, operation, and heat performance are exceptional. For an example of the application of the foregoing analysis, take the data presented in the paper, as follows:

The temperature at the back tube sheet = 2080 = $t_2 = ct_1$. For the small tubes the value for $c = 0.654 + 0.00143\,G$. Since the value of G (combustion rate) is not given, it must be determined as $2080 = (0.654 + 0.00143\,G)(1660 + 70\sqrt{G})$, whence $G = 133$ lb. coal per square foot of grate area per hour. Then, using the first equation, the firebox temperature is found to be $t_1 = 1660 + 70\sqrt{133} = 2470$ deg. fahr. (All temperatures in this discussion are on the Fahrenheit scale instead of on the absolute scale.) If the value for the combustion rate (133) is substituted in the foregoing equation, the value of c becomes 0.844 and $t_2 = 0.844 \times 2470 = 2080$. Notice that as the combustion rate increases the value of c increases, which produces the same increase in the temperature and heat transfer in the tubes as an increase in the W/p ratio of the paper. Substituting the length of the tubes, 20.8 ft., in the t_x equation, the temperature at the end of the tubes is found to be $t_x = 2470\left(\frac{0.654 + 0.00143 \times 133}{1.00 + 0.110 \times 20.8}\right)$ = 635 deg. fahr., and changing the length factor from 0.11 to 0.098 and the c factor from 0.654 to 0.600, the temperature at the end of the superheater flues is found to be 680 deg. fahr. The final temperature in the smokebox depends upon the relative gas-carrying capacity of the two sets of tubes, which, according to the paper, is in the ratio of 0.598 to 0.402, making the gas temperature in the smokebox about 655 deg. fahr. The registered smokebox temperature at a combustion rate of 133 lb. for this locomotive was 659 deg. fahr., as reported in the Bulletin of the Franklin Institute on superheater tests of this locomotive. The paper gives this temperature 620 deg. fahr., which is a difference of 1.55 per cent expressed in heat units.

Using the $S°$ equation with a factor of evaporation of 1.23 for a feedwater temperature of 50 deg. fahr. and a pipe cross-sectional area of 32.64 sq. in., the temperature of the superheated steam is found to be 663 deg. fahr. instead of 670 deg. fahr., as given in the data.

Design and Application of Rail Motor Cars

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The rail car is capable of performing certain services to better advantage than motive power of any other current type. It is not a competitor of the locomotive in the locomotive's proper field. It is capable of performing services within its scope at a cost and with an availability and reliability at least equal to other railroad equipment.

Satisfactory operation depends on correct design, correct application, proper handling by the operators, and intelligent and thorough maintenance. The maintenance should be in the hands of an intelligent, properly trained supervisor, who has sufficient authority to handle his work without clearing details through other officials. The design must be such that all wearing parts are renewable, at the minimum of expense, and with a minimum of time out of service. The exhaust valves are apt to require attention more frequently than other features of the engine, therefore the design should be such as to give maximum exhaust-valve life. Twin exhaust valves have been found desirable for this purpose.

Cooling systems must be designed to operate effectively regardless of car speed or direction. Transmission equipment should be capable of delivering to the rails the maximum possible percentage of engine power throughout the range of car speeds, at least to 60 m.p.h. The parasites and accessories can be handled to best advantage by the use of a small separate power plant. Cars of current designs are proving their worth in millions of miles of service annually on many different railroads in various parts of the world. The rail car is generally accepted as a proved tool for the reduction of operating costs and improvement of service within its field.

This paper gives the field for application of motor cars, some problems of design and use, and conclusions as to design, operation, and maintenance.

WHILE the rail motor car is not new, having been commercially introduced during the early part of the present century, it was not accepted as an important unit in the economics of rail transportation until very recently. During the past seven years the development has been extremely rapid. Designs have been improved, sizes have been increased, the scope of application has materially broadened, and it has come to be recognized as having a definite field wherein it is superior to other forms of motive power.

Scope of Application

Rail motor cars are at the present time in daily service in sizes ranging from single cars developing about 70 hp. and weighing about 15 tons, to 800-hp. cars, capable of handling a number of trailing cars. Even larger sizes are being discussed at the present time. Cars now in successful service cover a field broader than any advocate would have dared predict as recently as five years ago. The sizes using power plants of 200 hp. and less are generally arranged with mechanical transmission. Usually they are limited to use as single cars, or at most, with one comparatively light trailing car, and are produced at the present time principally for export. Cars ranging from 250 hp. upward are practically all of the gas-electric type. A great majority of the cars being produced for the American market at the present time are of this type.

It will be readily seen that the range of sizes is adequate to cover a wide variety of conditions, as a result of which rail motor cars are now being successfully used in at least the following classes of service:

1 Branch-line passenger, baggage, express, and mail service.
2 Local main-line service requiring trains of from one to four or five standard cars.
3 De luxe express service where trains are limited to three or four cars.
4 Milk train service.
5 Local freight service on light lines.
6 Mixed train service on light lines.
7 Both light and medium switching service.

Typical successful applications have demonstrated the practicability of this service in the respective fields.

Why Use of the Rail Motor Car Is Justified

Among the more important considerations which have led to the use of rail motor cars, are the following:

1 Low cost of operation. In practically all applications of rail motor cars, savings in operating cost have been effected.
2 Properly maintained, the motor car is capable of performing an exceptionally high percentage of its scheduled mileage. This class of equipment can be kept available for service a higher percentage of time than steam equipment. Averages from a number of different properties indicate an availability of about 93 per cent, with many individual cases above 95 per cent.
3 Again assuming proper design and maintenance, the motor car is thoroughly reliable, and can be depended upon to complete its schedules.
4 The maintenance cost is comparatively low.
5 Stand-by losses are much less than with steam equipment as it is not necessary to maintain hostling service or burn fuel during a layover.
6 Due to the absence of cinders and smoke, the equipment can be kept clean and attractive to the public.
7 A given equipment properly designed can be adapted to a considerable variety of service.
8 Under some conditions, as for instance the complete motorization of a branch line, the expense of dock and terminal facilities can be eliminated.

Relative Responsibilities of Manufacturer and Operator

The success of the rail motor car in performing any service depends upon satisfactory design, satisfactory application, proper operation, and proper maintenance. Satisfactory design is the problem of the manufacturer. The manufacturer can assist in the proper application of the equipment. The correct operation and satisfactory maintenance of the cars is a problem entirely in the hands of the railroad, although the manufacturers are glad to assist in any way possible.

The design is and properly should be the function of the manufacturer. By reason of the engineering, sales, and servicing staff which he maintains, he is constantly in touch with rail-motor equipment throughout the world, and is in a position to profit from experience gained in all sorts of applications. Furthermore since the manufacturer is selling his product to many different railroads to meet many different conditions, he is compelled to spend sums in development far beyond what any given railroad might reasonably spend for the same development. Also by reason of the time and care which the manufacturer can and does necessarily take in the development of new apparatus, he is able to turn out a properly coordinated, well-balanced unit,

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Contributed by the Railroad Division and presented at the Annual Meeting, New York, N. Y., Dec. 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

which would hardly be possible for any railroad to do without undue expense, test, and experimentation.

A great deal of emphasis could profitably be placed on the importance of proper balance and coordination between the various units which enter into the make-up of a complete self-propelled car. It would seem reasonable to expect that a better product, more thoroughly adapted to its purpose, can be had when purchased as a complete, trademarked, predesigned, and pretested equipment, than is possible where an attempt is made by the railroads to specify certain features, which obviously upset the balance of the whole. It is felt certain that no one would purchase an automobile or a motor truck, and attempt to specify special features in the engine. True enough, the purchaser will and rightly should determine the arrangement of body that is wanted for his work. The same should follow in rail-car design, but in the essentials, the design as offered by the manufacturer, both as to power equipment and general car design, should be used, and he should in turn be held responsible for the proper performance of such an equipment, when operated in accordance with the conditions agreed upon. Obviously also, if the manufacturer is able to manufacture parts in quantities, carry them in stock, and build to an existing design, which has been proved and with which his engineers, workmen, and service men are familiar, the product can be delivered at a far lower price than where special designs are attempted. The purchaser will get a better product at a lower price, and with less chance of trouble in service, if a complete, trademarked, manufacturer's design is accepted.

On the question of proper application, the manufacturer can be of considerable assistance to the railroads in selecting proper equipment for a given service; in fact, when the railroads so desire, the manufacturer is entirely willing to select and guarantee the proper equipment to meet a specified service. However, it is entirely within the province of the railroad to see that the actual application is reasonably in accord with the recommendations of the manufacturer. Proper application has a great deal to do with the success of this class of equipment. If the equipment is grossly overloaded, obviously failures in service and maintenance expense will be all out of proportion to the service rendered. There is, however, another side of the picture, in that if too large for a given service, the equipment will be running at such a low load factor that economy of operation will be lost. It is not the desire to convey the impression that the application of any given equipment must be within very narrow limits. Quite the contrary is the case in fact. Any given equipment can acceptably cover a rather broad field.

Satisfactory operation of rail motor cars is not at all difficult, in fact modern designs are so arranged and functions are so interlocked one with the other, as to make the equipment more or less fool-proof. Nevertheless, the operators should be thoroughly instructed and properly qualified, just as is the practice for steam-locomotive engineers.

The fourth, and in the long run probably the most important of the factors entering into successful operation, is maintenance. It is not necessary to say to a group of engineers that any mechanical equipment requires a certain amount of maintenance. There are many cases of cars in service which have averaged 95 per cent availability over a period of several years, whereas other cars of identical design have had a far lower factor of availability primarily because of the difference in maintenance. In this field, the manufacturer attempts, by offering technical advice, by maintaining a proper field staff, and by the preparation of voluminous instruction books, to assist the mechanical departments of the railroads, but after all he can only assist. The burden of the job is and properly should be carried by the mechanical officials of the railroad. It is not the purpose to dwell on this phase at any length, but it does seem advisable to point out that on an internal-combustion engine, and for that matter on the transmission equipment as well, if the proper thing is done at the proper time, maintenance expense can be kept surprisingly low, whereas if some minor adjustment is neglected, heavy expense may follow. In this respect this equipment differs rather widely from steam equipment. The steam engine can be operated, inefficiently it is true, but nevertheless without failure, even though much needed repairs are postponed. If some very minor inspection functions on an internal-combustion equipment are neglected, comparatively heavy repairs may be required, otherwise, a road failure may result. This point can be well illustrated by mentioning cleaning of gasoline-line filters and oil filters, checking and setting of magneto points and spark-plug points, and the correct setting of valve clearances.

Experience shows that when cars are first introduced on any property or division, troubles are far greater than after some months of service, in spite of depreciation of the equipment.

The railroads which have had the best results in the use of motor cars recognize that the maintenance of this class of equipment requires the services of men who are specialists in this work. They must have had sufficient experience with the internal-combustion engine, and know enough about the electric-transmission equipment to handle adjustments and repairs intelligently. These men should be under the supervision, direct or otherwise, of a thoroughly qualified supervisor. Satisfactory operation in all its phases probably depends more upon intelligent supervision and maintenance than any other one thing. This supervisor should have authority to direct engine-house and shop personnel, pass on qualifications of operators, place minor orders for repair parts, and in general be permitted to handle the routine of maintenance without delay, interference, or the necessity of clearing through a number of officials or departments. It will be found that when so set up, assuming the men to be properly qualified, the total maintenance expense can be kept to a minimum, and a large portion of such expense will be expended in minor adjustments, inspection, etc.

Design Requirements

The designer should bear in mind the following requirements: (1) As near absolute reliability as possible, (2) maximum availability for service, (3) long life, (4) performance, (5) ease of adjustment and repair, (6) simplicity, (7) low maintenance cost, (8) low first cost, and (9) light weight.

In view of the very rapid progress which has been made in the past few years, one would be rash indeed to attempt to set out an arbitrary specification, and insist that it covers the last word in rail-car design, either as to power-plant or transmission equipment. Nevertheless, the experience which has been accumulated indicates certain trends, which should be given serious consideration in determining good design.

Obviously, no one size or type of equipment will meet all varying conditions of service any more than a given type of steam locomotive meets all types of steam service. The equipment must continue to vary in size, also in the relation between tractive effort on the one hand and speed on the other, depending upon the particular service in which it is to be used. It would be very desirable if a given railroad could standardize on one type and size of equipment, maintaining interchangeability of parts, etc., but that will not be possible if the equipment is to be used throughout the full field to which it is adapted.

Various kinds of power equipment have been built for rail-car work, including steam plants of various types, and a number of Diesel equipments. The experience with steam plants has been limited to one or two cars. A considerable amount of pioneering work has been done with Diesel-electric power plants, particularly on the Canadian National Railroad. It seems that for con-

ditions within the United States, the Diesel cannot as yet be classed as a competitor with the carburetor-type engine for rail-car work. Due to the extremely high pressure involved in Diesel operation, either the weight per horsepower must be higher, or the maintenance more expensive, and the reliability less than for a corresponding gasoline engine. For the present at least it has not been accepted for our conditions. In this paper, therefore, only the carburetor-type internal-combustion engine will be considered.

General Design

While the weights of rail motor-car equipments are constantly being increased, because of the higher horsepower of the new models, and the heavier trains in which they will run, it is, nevertheless, important that the weights of these trains be kept to the minimum. A given power plant can meet a given schedule with a fixed gross tonnage. Obviously the lower the weight of the train itself the more net load can be carried, or conversely, if the train weight can be kept lighter, the requirements, and consequently cost of operation, are reduced. Surplus weight costs approximately one-half cent per ton per mile to handle.

When considering the relation of engine horsepower to train weight, the efficiency and factor of utilization of the transmission equipment must, of course, be taken into account. Generally speaking, fast schedules can be made with weights of from 400 to 600 lb. per horsepower, and average schedules with weights as high as 1000 lb. per horsepower.

The conditions under which rail-car engines operate are in many respects very favorable. The engine can be kept at desired operating temperature while in service; it can be kept at least reasonably warm during layover by means of the car heater, thus avoiding the ills incident to frequent cold starting; the oil temperature can be maintained substantially constant; the intake air for the carburetor is reasonably clean and at a moderate temperature; the engine need only run wide open at its designed speed; and finally, when using the electric transmission, the connection between the engine and the ultimate load is elastic, thus preventing transmission of shock.

In some other respects the conditions to be met are far more severe. The engines are expected to operate more miles before the valves are ground than many automobile engines will run during their life. The engines should also be capable of operating the maximum length of time between overhaul periods. A fair figure for recent designs is about 6000 hr., or 150,000 miles. The engines operate with a comparatively high load factor, and with comparatively high water-jacket temperatures, making necessary careful attention to cooling details. When all of these things are taken into account it is evident that engines to give the best results must be specially designed with the conditions of this service definitely in mind.

Engine Ratings

It is undesirable, at the present time at least, to attempt any arbitrary formula for rating engines for this class of service. The designs offered by different manufacturers vary so widely that any formula based on bore, stroke, number of cylinders, and piston speed is very apt to be misleading. Too many factors which must be taken into account, are omitted in any such arbitrary formula. Naturally the railroads would like some yardstick whereby the power plants which they buy for this class of service can be checked as to rating. No engine can be expected to develop throughout its life in normal service, the maximum horsepower which it is capable of developing under laboratory conditions. It seems, therefore, that a service rating should be given these power plants somewhat below the power actually developed on test, because of the depreciation in power which may be expected in service. The following is suggested as a simple and reliable means of rating:

For rail-car service, engines are to be rated at a speed which the manufacturer is willing to guarantee for continuous duty, and at 90 per cent of the actual power developed on test when operating at that speed. This practice has been followed by one prominent producer for several years, and has given uniformly satisfactory results; in fact engines tested after 150,000 miles in service and previous to any overhauling have developed power somewhat in excess of the rating thus determined.

Engine Speeds

There has been a trend during the past several years toward increased operating speeds on internal-combustion engines of all kinds, particularly for automobiles, trucks, and bus service. This same trend should logically be followed in rail-car work. Considering that other things are equal, the power output of a given engine is more or less directly proportional to speed, it is obvious that the engine should be used and rated at the maximum speed consistent with satisfactory life and reliability. Increase in power from a given engine secured in this way does not materially increase the first cost, either of the engine or the generator to which it is attached. It may be true that to operate at these higher speeds, the bearing loads are somewhat increased, but this is considered in bearing design, and is partly offset by careful balance and the use of aluminum pistons, thereby reducing reciprocating weight; in fact when light-weight reciprocating parts are used and considering centrifugal, inertia, and gas-pressure loads, the net load on the bearings is frequently less at higher speeds. In any case it is only necessary to provide adequate bearings. At the present time the limitation as to speed seems to rest more in satisfactory life and functioning of exhaust valves, than in bearing loads or piston speeds. The engines on the present market for this class of service, vary in average piston speed from about 1200 to 1800 ft. per min. Engines using twin exhaust valves, thereby improving valve conditions, are ordinarily rated at about 1650 ft. per min.

Engine Life

It has been the practice of railroads using motor cars, to depreciate the engines on the basis of a life of eight to twelve years, while depreciating the car and trucks on the usual basis as determined by I.C.C. rulings. In view of the progress which is being made in this field, this basis may be fair from the standpoint of obsolescence; however, all modern engines used in this class of service are designed for the ready renewal of bearings, pistons, rings, cylinder liners, valves, and other wearing parts, so that there is apparently no reason why these engines should not last more or less indefinitely, if proper renewals are made from time to time.

Fuels

The vast majority of all rail motor-car engines in service are designed for and operate with gasoline as the fuel. At the present time there is no power plant which can compete with the gasoline engine from the standpoints of weight, first cost, maintenance cost, reliability, and ease and flexibility of operation and control. Certain Western roads have adapted the carburetor engine to the burning of less volatile fuel, commonly known as distillate, by the use of special carburetors. This fuel can ordinarily be purchased at the refineries, under proper specifications as to sulphur, etc., at a price of some 4 cents per gallon less than gasoline. In addition to this saving in the cost of the fuel itself, the highway tax on gasoline widens the differential to as much as 8 or 10 cents per gallon in such states as do not rebate the tax when used for other than highway purposes. Obviously the saving in

fuel cost becomes quite attractive, particularly where the tax is involved. The use of distillate as a fuel introduces additional complication in the carbureting equipment, and requires additional skill in the handling and maintenance of the apparatus. It also results in a considerably more rapid dilution and deterioration of the lubricating oil, necessitating changing of oil at frequent intervals. It is also necessary in burning the heavier fuel to reduce the compression of the engine, thus somewhat lessening the horsepower, which in turn increases the per-horsepower

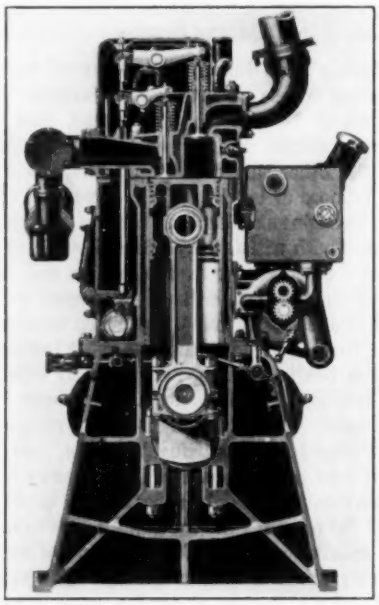


FIG. 1 CROSS-SECTION THROUGH SIX-CYLINDER BRILL MODEL 660, OR EIGHT-CYLINDER MODEL 860 ENGINE

cost of the power plant. It seems probable that distillate will be used where the railroad has a sufficient number of cars and a sufficiently well-trained personnel properly to handle the additional complications and servicing required. This will be especially true of the Midwestern roads, where distillate can be secured from refineries on their own lines. Apparently, however, unless these conditions obtain, the moderate saving in fuel cost is not sufficient to justify the additional maintenance expense and supervision which may be required.

A considerable effort is being put forth at the present time to improve methods of burning distillate as a fuel, and it is possible that some of the present objections may eventually be eliminated, in which case the use of this heavier fuel may become more general.

CYLINDER HEADS AND VALVES

In a rail car, as well as other internal combustion engines, the need for regrinding exhaust valves is usually the first thing that makes it necessary to remove an engine from service, therefore anything that can be done to increase the life of exhaust valves, materially increases the availability of the engine. Furthermore, the temperatures of the exhaust valves and exhaust-valve seats are largely responsible for limiting the compression which can be used, and consequently the power output and economy. The cooler the exhaust valves can be kept, the longer will be the time between regrinding periods. The heat of the valve head is dissipated primarily through the seat, and the greater the distance from the center of the head to the seat, the hotter will be the center of the valve head. Further, the area of the valve head exposed to heat increases with the square of valve diameter, whereas the cooling surface increases only in direct proportion to the diameter. Therefore, the smaller the valve, the more will be the cooling surface on the seat in proportion to total exposed area. These considerations have led to the use of twin exhaust valves in preference to one large valve, in most engines of more than 5-in. bore. In addition to securing longer valve life, considerably more power can be taken from the engine without undesirable results.

Twin intake valves are generally used, partly because they permit a higher volumetric efficiency due to more complete filling, but also because it makes possible interchangeability between intake and exhaust valves.

The majority of engines used in rail-car work are of the overhead-valve design, with the combustion chamber contained in the head. On most designs in general use at the present time this combustion chamber is of a generally cylindrical shape. In modern automobile engines the combustion chamber is designed so as to give a high turbulence to the charge during the compression and firing strokes. This arrangement has certain decided advantages in decreasing detonation and insuring complete mixture, vaporization, and burning of the charge, and consequently in further increasing exhaust-valve life. A recent design of rail-car engine, as shown in Fig. 1, uses four overhead valves per cylinder, but locates the intake and exhaust valves at different levels, thereby achieving the high turbulence design generally used on automobiles, but without sacrificing the advantages of four overhead valves per cylinder. It is expected that this design will permit higher horsepower output, smoother operation, longer exhaust-valve life, and in the case of slow-burning fuels, will materially improve fuel consumption. This arrangement also makes possible a very convenient arrangement for camshaft and rocker arms, also insures a thorough distribution of cooling water around exhaust valves, exhaust ports, and spark plugs. Also due to

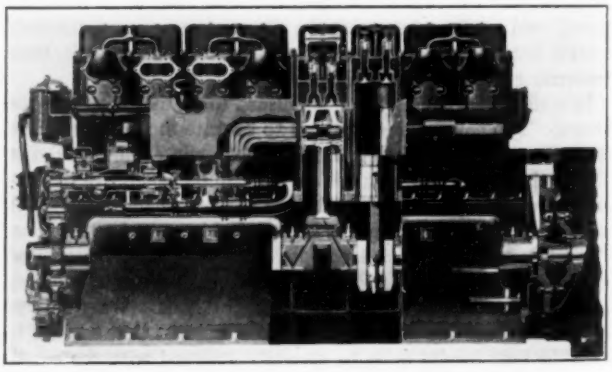


FIG. 2 LONGITUDINAL SECTION BRILL MODEL 860-535 HP. RAIL-CAR ENGINE

the compact arrangement of the combustion chamber and the thorough mixing of the fuel with the air, only two spark plugs are required. Three or four spark plugs are required even in engines of smaller size when using the conventional combustion chamber. In this same design the two exhaust ports have been kept entirely separate, which represents a distinct improvement from the standpoint of cooling. (See Figs. 1 and 2.)

CRANKSHAFT, BEARINGS, AND OILING SYSTEM

Generally speaking, all engines on the present market are satisfactory from this standpoint. It has been observed, however, that bearing replacements, when finally required (usually after 60,000 to 150,000 miles), are made necessary not by reason of excess wear, but rather because of the babbitt cracking loose from

its support. This cracking almost invariably starts where anchoring dowels, screws, or rivets go through the bearing. Dowels and similar locating devices are also undesirable, particularly in the crankcase half of the main bearing, because it is impossible to remove the dowels, and hence a bearing for replacement without removing the shaft from the engine. In the new design illustrated, therefore, the cap half of both main and connecting-rod bearings has a thin layer of babbitt cast into the cap itself. The crankcase half of the main bearings, and the rod half of the connecting rod bearings are heavy bronze backed, babbitt lined, removable shells. Due to the thickness of these shells the cap abuts the ends of these at the joint, thereby securing the loose half of the bearing without any dowels. This makes possible a smooth unbroken bearing surface without reliefs of any kind, which should not only improve the condition as to cracking, but also, due to the absence of reliefs, insures longer bearing life because the oil cannot as readily be squeezed out of the bearing under shock loads. Also the case half of the main bearing can be readily removed without disturbing the shaft.

All modern engines in rail cars carry high-pressure lubricating systems. They vary in several essential details, however. In the new design to which reference is made, a hole is drilled longitudinally through the crank-pin bearings, thus reducing adjacent main-bearing loads by as much as 1300 lb. per bearing, at the same time providing an oil reservoir. The oil is introduced into the main bearings, and thence into the crankshaft through the bearing caps, i.e., on the low-pressure side of the main bearing. A considerable quantity of oil beyond actual lubricating requirements is circulated through the crankshaft, and allowed to escape through a pressure-regulating valve, thus materially assisting in the cooling of bearings. The crankshaft is drilled from end to end so that even though one or more of the supply lines be obstructed, oil to all bearings is assured.

A suitable inter-cooler, or other provision, should be made for maintaining the oil temperature high enough to boil off as much dilution as possible, but low enough to prevent excessive oxidation of the oil. Satisfactory results have been had when the oil temperature is maintained between 150 and 170 deg. fahr. The use of a satisfactory oil filter is important. If good oil at the proper temperature is used, the matter of changing oil when using gasoline as a fuel is practically a question of contamination or dirt. With a filter consisting of a series of felt stacks, through which the oil is passed edgewise through felt washers, all dirt but the finest particles in suspension can be removed. With such a filter oil has been used for as much as 4000 miles between changes with entirely satisfactory results.

If the temperatures are not correctly maintained within a reasonable range, or if the filter is inadequate, or in any case when burning distillate without heat, more frequent changes are necessary, sometimes as frequently as once in 500 miles.

Cooling Systems

The cooling system should be designed so that the car will cool equally well when running in either direction and at any car speed, and should be such that the correct temperature can be maintained regardless of atmospheric temperature. This can be accomplished best by using forced-draft circulation of the cooling air through the engine radiators with electrically driven fans arranged for a variable-speed control so that the cooling capacity can be set to suit the conditions. The cooling system should be arranged so that all water automatically drains inside the car whenever the engine is shut down. This makes it unnecessary to drain the system to prevent freezing, as cooling water inside the car can be kept warm during layover periods by means of the car heater.

The air from the radiators should be discharged upward adjacent to the exhaust discharge, in this way carrying any obnoxious exhaust gases into the air, and preventing their being drawn into the car windows. (See Fig. 3.)

Exhaust Systems

Due to the intense heat developed in exhaust manifolds and pipes when the engine is running for long periods at a high power

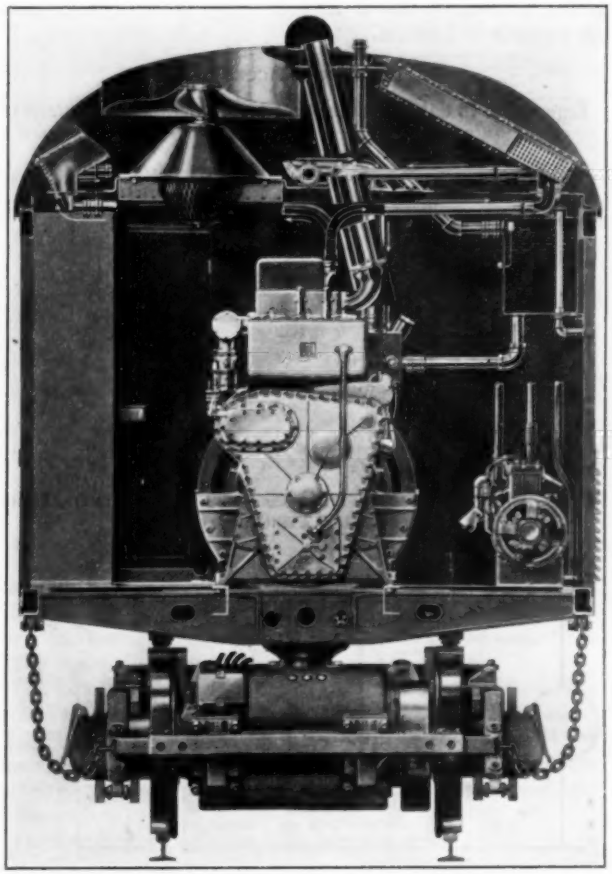


Fig. 3 Section Through Brill Model 860 Car, Showing Cooling System, Exhaust System, Front View of Main Engine, Location and Arrangement of Auxiliary Power Plant

factor, discharge should be as direct as possible. The exhaust manifold should be made as simple as possible, as experience has indicated that intricate castings are certain to make trouble. This has been satisfactorily overcome in some cases by using a high chrome-content cast steel. The simplest method seems to be the use of a separate exhaust manifold for each port, entirely eliminating any chances of cracks. For use in congested areas, at least a partial muffling of exhaust is necessary.

Fuel-Feeding Systems

Various fuel-feeding systems have been used. None of them have been entirely satisfactory. With pressure or gravity systems there is always danger of flooding the engine room in case of a leaky or dirty float valve in the carburetor. Vacuum feeding systems working off of the intake manifold, as commonly used in the automobile, are not satisfactory as the source of vacuum when the engine is running wide open is inadequate. A separate pump on the engine as a source of vacuum has been used with fair success, but is open to the criticism that loose connections or other

disturbances in the system may render it inoperative. Mechanical pumps driven from the engine have not been entirely satisfactory due to difficulty of maintaining stuffing boxes on plunger types, and the short life of diaphragms or bellows in those types. Considerable work is being done at the present time to render the vacuum system less susceptible to derangement. If these shortcomings can be corrected it represents the ideal system. There is also the possibility of using a series of small electrically driven pumps, so arranged that if one goes out of order the remainder will continue to function.

Duplication of Accessories

Experience to date indicates that a considerable percentage of failures in service result from the failure of minor accessories, rather than failures of the basic parts of the equipment. For that reason good practice provides for duplication of such accessories as fuel-feeding devices, magnetos, spark plugs, carburetors, and similar parts, so that even though one part may fail the car can at least complete its run.

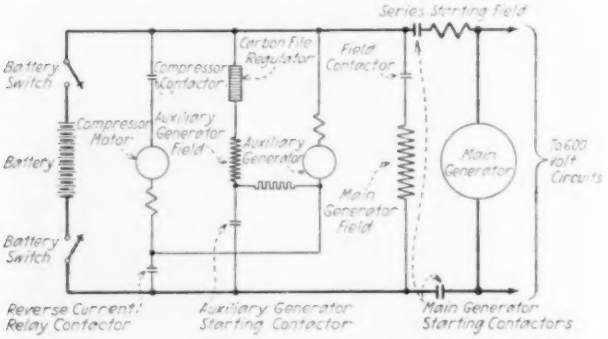


Fig. 4 Schematic Wiring Diagram of 32-Volt Circuits, Brill Model 660 and 860 Cars

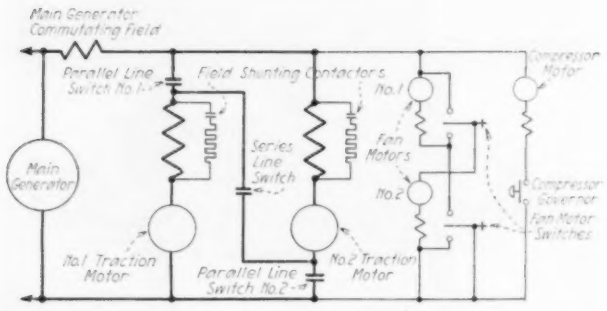


Fig. 5 Schematic Wiring Diagram of High-Voltage Circuits, Brill Model 660 and 860 Cars

Furthermore, apparatus should be arranged, if possible, so that a failure of one part will not affect another. As an illustration, when cranking the main engine under unfavorable conditions the battery voltage may drop considerably, thus making battery ignition somewhat difficult. The use of magnetos prevents trouble from this cause.

Electrical Equipment—Loading Characteristics and Accessories

In the essentials, electric transmissions are all alike. In each case the engine drives a direct-current generator, which in turn transmits power to one or more series motors. The variation between different systems comes in the means of handling the accessories, the generator control, and the switch gear for properly connecting the traction motors, i.e., to say, reverse or forward and series, parallel or shunted-field connections of the traction motors. In the matter of motor connections, the simplest scheme is the so-called "K" control, in which the operator manually operates a controller, setting up power circuits in the proper fashion directly. This has been used particularly where low first cost was a serious factor. In the other system the motor connections are handled by contactors remotely controlled from the operator's position. This type of control is universally used where heavy currents are to be handled, as for instance in electric-locomotive applications. It has the disadvantage of somewhat higher first cost and somewhat more complicated wiring, but has advantages in that 600-volt potential can be kept entirely away from the operator, and further in that contacts are made or broken at high speed and are maintained under high pressure, thus reducing the tendency to burn. Both systems have given good results. With the trend to constantly increasing horsepower, the contactor or remote type will undoubtedly gain favor for the reasons given. This arrangement has a further advantage in case of double-end control or double power-plant cars, in that the heavy current-

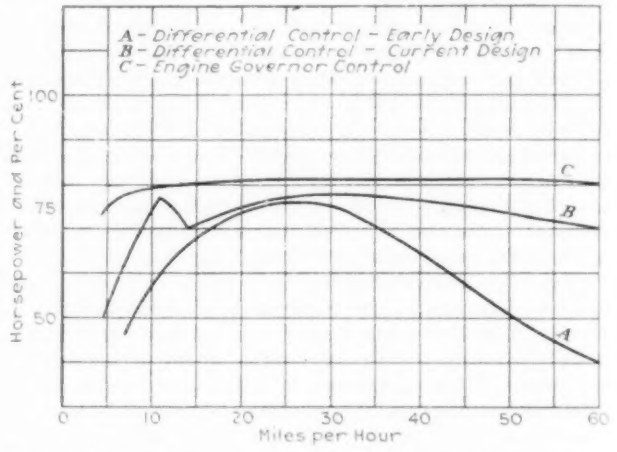


Fig. 6 Graphs Showing Progress in Electric Transmission Design From the Standpoint of Power Utilization

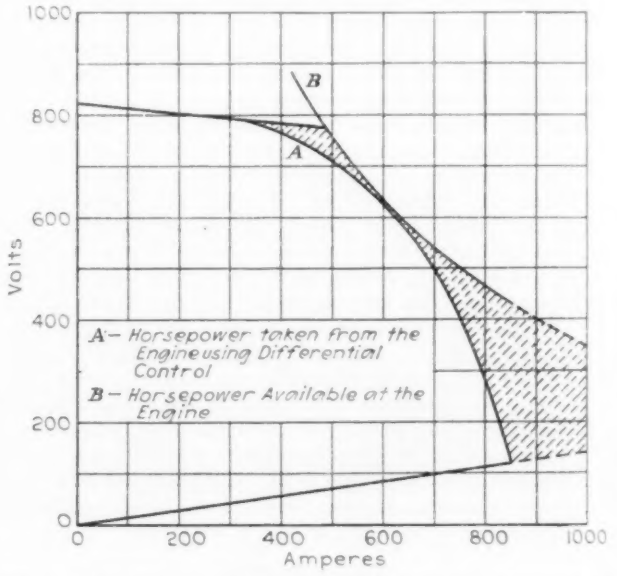


Fig. 7 The Principal Additional Performance Secured by Governor Control Is the Result of Increased Utilization, Rather Than Increased Efficiency

carrying cables need not be carried throughout the length of the car as is the case with "K" control. This equipment has the further advantage that transition can be made from series to parallel connections of the motors without closing the engine throttle. This can also be done with "K" control if skillfully handled, but it is general practice to close the throttle when making such transition with "K" control.

The function of the electrical transmission is obviously to transmit the full power of the engine to the wheels at all times, regardless of car speed, motor connections, or other conditions outside the engine. With differential control of the generator field, such as has been generally used by all builders in the present market, the inherent characteristics of the generator and of the traction motors prevent full utilization of the engine horsepower at all times, although it does approximate it.

Marked progress in electric-transmission design has been made during the past five years. Fig. 6 shows graphically engine horsepower in percentage against miles per hour. The engine is capable of developing 100 per cent of its power rating at all car speeds. In early designs a comparatively small percentage of the power thus developed reached the wheels, as shown on graph "A." The equipment in general use at the present time delivers to the wheels power approximately in accordance with graph "B." The equipment designed for engines shown in Figs. 1 and

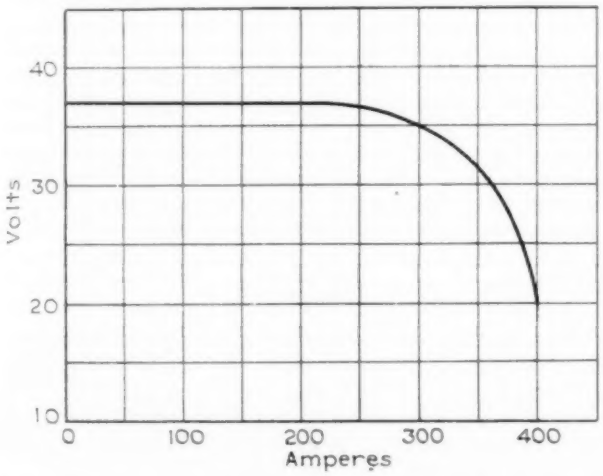


Fig. 8 The Auxiliary Power Plant Can Be Set at a Desired Voltage to Maintain Correct Battery Charge, and Will Operate Accessories Without Change in Voltage, Within the Limits of Its Output

2 will deliver power to the wheels in accordance with graph "C." This is brought about partly by increased efficiency in the electric generator and traction motors, but primarily in the improved design of the generator control, such that the generator utilizes the full power of the engine throughout the full range of car speeds. It is primarily a question of complete utilization, rather than a question of improved efficiency. In this design the generator is a simple, separately excited, shunt-wound machine, the current for this shunt field being supplied from the low-voltage system, to which reference is made later, through a rheostat or controller, which varies the field strength. This rheostat is in turn actuated by the engine governor, so that if the engine tends to run above its rated speed the load is increased, or vice versa. In a conventional equipment as generally used heretofore, the engine drives a main generator and an exciter. In these two machines there are at least five fields, all of which must be properly coordinated and balanced. When so coordinated and balanced they take a power output from the engine as shown in graph "A" of Fig. 7, assuming the power of the engine to be represented by graph "B." With the control system mentioned, additional power can be delivered as indicated by the shaded areas, and limited only by the commutating limit of the generator on the one hand and voltage limit on the other. Power delivered to the rail, shown as tractive effort at various speeds for engines il-

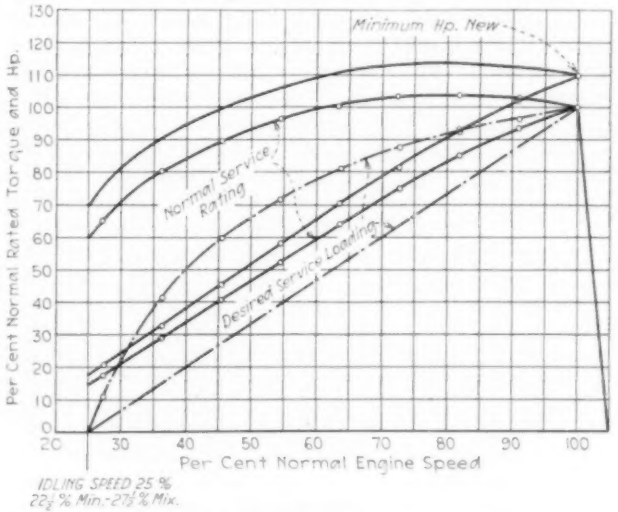


Fig. 9 The Most Desirable Loading Characteristic Extends in a Straight Line From No Load at Idling Speed to Full Load at Rated Speed

lustrated, is shown in Fig. 10. Further, in the conventional equipment the amount of load imposed varies as between hot and cold equipment, in this way preventing uniform loading of the engine under all conditions.

The power available from a given engine varies, depending upon its condition. With the governor-operated control arrangement the engine will be called upon to develop whatever power it is capable of delivering at its rated speed, and it is not necessary to reset the electrical load to suit changed conditions of the engine.

The carburetor engine is most efficient when running at or near wide-open throttle. Its efficiency is reasonably independent of speed. The fuel consumption per horsepower increases rapidly as closed throttle operation is approached. On the majority of runs the full maximum power of the engine is not required as an average condition, the average power factor probably being in the neighborhood of 60 to 80 per cent. The ideal condition, when reduced power is required purely from the standpoint of economy, would be to overload the engine, thereby reducing its speed and power; however this would be detrimental to the life of the engine, as operating at wide-open throttle and reduced speed would increase the maintenance. A happy medium between high fuel consumption on the one hand and excess maintenance on the other, is as indicated on Fig. 9. The desirable load extends from zero at idling speed to a maximum at rated speed, in a straight line. The use of an equipment which will give a loading characteristic of this nature will insure good economy when operating at less than full power, in that way representing a distinct advance over the conventional differential control equipment, without overloading the engine at reduced speeds to the detriment of the engine, in this respect having an advantage over any control arrangement which maintains a fixed torque. The best application is that which, at any given engine speed, loads the engine to the maximum torque which it can carry smoothly and without detonation or other unsatisfactory performance at that speed.

The steam locomotive is essentially a comparatively simple machine. In recent years, however, locomotives have been fitted with superheaters, feedwater heaters, boosters, and numerous other accessories to increase their effectiveness. Rail cars must necessarily follow the same general line of development particularly if the added efficiency can be obtained without added complication. In the case of the equipment given, a 550-hp. engine will perform the same schedule, with full utilization per graph "C," Fig. 6, as a 600-hp. engine with the utilization as indicated by graph "B." Power in the engine is of no use unless it be transmitted to the rail. Further and also important, since

ENGINE MODEL	No. 660	No. 860
HORSEPOWER	400	535
GEAR RATIO	56-20	56-20
WHEEL DIAM.	36"	36"

TRACTIVE EFFORT	400 HP. AMPS.	400 HP. VOLTS	535 HP. AMPS.	535 HP. VOLTS
22,000	---	---	780	430
20,000	740	345	725	465
18,000	685	370	675	500
16,000	625	405	615	550
14,000	570	450	550	605
12,000	505	505	495	675
10,000	445	570	430	385
8,000	375	665	375	455
6,000	310	410	305	560
5,400	280	450	280	600
4,000	240	530	285	585
2,000	200	630	---	---

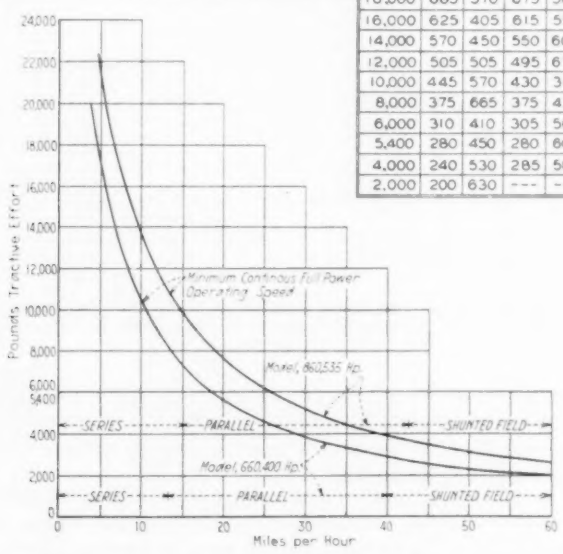


FIG. 10 BY REASON OF COMPLETE UTILIZATION OF ENGINE POWER, RELATIVELY HIGH TRACTIVE EFFORT IS AVAILABLE AT ALL CAR SPEEDS

the engine is working somewhere near its point of maximum efficiency, the fuel consumption will be less.

Ordinarily various accessory devices, such as battery, exciter fields, car fans, car lights, air compressor, etc., must be supplied with current at 32 volts. With equipment as generally used heretofore, this has been supplied, although rather imperfectly, either from the main generator or from the exciter. By reason of the characteristics of the differential control machine, the exciter is inherently a variable-voltage machine, and therefore, scarcely suited as an ideal source of 32-volt current for accessory purposes. If, on the other hand, the exciter is made a constant-voltage machine, it is capable of delivering only its full voltage when operating at two-thirds of rated speed or higher, unless it be made extremely large, which introduces prohibitive costs.

It is extremely important that the battery be kept in good condition, as the whole performance of the car depends upon it. In spite of auxiliary starting devices such as compressed air, the engine must after all be started, as for instance, after an overnight layover, by using the battery as a source of power.

Also there are many conditions where it is necessary to maintain air pressure for braking purposes, where otherwise the engine would not be needed. With the typical differential control it is necessary in such cases to disconnect the traction motors from the circuit and speed up the engine for the purpose of supplying five or six horsepower necessary to operate the air compressor. This obviously is objectionable from the standpoint of wear and tear, to say nothing of fuel economy, but the most serious objection is that the operator must willfully perform certain functions to insure an adequate supply of air for the safety of his train.

In view of the above requirements as to battery-charging and air-compressor operation, arrangements have been made whereby these functions can be handled from the main engine while idling. A number of such equipments are in service, and represent a distinct improvement in respect to these accessories over previous practice. These equipments, however, require elaborate control apparatus.

In the new design to which reference is made, a small industrial-type four-cylinder vertical engine, direct connected to a 32 to 40-volt generator, is used for battery charging, and the handling of such parasite loads as air compressor, lights, train control, excitation, etc., thus entirely segregating the low voltage system from the main plant and the high voltage system. In this way a small generator thus driven can be maintained at constant voltage, giving ideal battery-charge conditions, in addition to handling such accessories as may be required. Obviously the main engine can be shut down under many conditions where it would not otherwise be possible. Further, the small engine can be used as an additional source of power for starting the main engine. In case it is desired to supply a limited amount of current to trailing equipment, this can also be supplied from this small power plant. It will be seen, therefore, that the segregation of the low-voltage and high-voltage circuits, generally as shown schematically in Figs. 4 and 5, considerably simplifies the apparatus, and at the same time improves the functioning of both plants. While this, of course, adds to the cost of the equipment, the results in safety, decreased complication of the main transmission, less wear and tear on the main engine, added assurance of an additional source of power for starting the main engine, and numerous other incidental advantages, seem to justify this added expense.

Discussion

HUGO MOREN.[2] As the author pointed out, the Midwestern roads are burning distillates, which they obtain from refineries on their own lines. Their gasoline engines are fitted with special carbureters and vaporization devices. This way of burning fuel oil is inefficient and costly to service and maintenance, and consequently the savings, if any, are small.

Due to the necessarily lowered compression ratio, the power output and flexibility are less than with ordinary gasoline engines. As the combustion is incomplete, the engine smokes and the fuel consumption is excessive.

An oil-burning engine of the low-compression type has been developed recently in Europe. It has a considerably lower compression ratio than a Diesel engine, but slightly higher than a good gasoline engine. It starts on gasoline and retains the electric ignition not only for the start but for continuous running. It has a solid-injection fuel system, which distributes the fuel with great uniformity. This European engine has the advantage of a remarkably low fuel consumption under load, but at low speed and at idling the combustion is rather incomplete. It has to use gasoline for the start.

Properly developed, an engine of this kind could be made to start without using gasoline, and after a few minutes' running the first inevitable smoke would disappear, even when the engine is idling. In order to facilitate idling and avoid crankcase-oil dilution, the injection-fuel pump will be so designed as to cut out a variable number of cylinders, whereby the others will

[2] High-Speed Diesel Engineer, American Machine and Foundry Company, Brooklyn, N. Y. Mem. A.S.M.E.

have to pull hard enough to keep up the temperature in the combustion chamber.

An engine of this kind will have as good a flexibility as any internal-combustion engine. It will develop more power than a corresponding gasoline engine. It will have as good fuel consumption as a good Diesel engine (0.42 lb.). There would be no limit as to size of the cylinder; a 12-in. cylinder will not present greater difficulties than an 8-in. cylinder. Finally, this engine would be lighter and cheaper to build than a corresponding Diesel engine. It can easily be imagined what an immense field of application there would be for an engine of this kind.

The combustion system need not be confined to the four-cycle principle.

HERMANN LEMP.[3] The paper is a valuable contribution to the application of internal-combustion engines to railroad service in connection with electric drive.

Years ago, in discussing with Mr. Henry Chatain the control situation, he was eager that some way could be found to produce automatically the electrical energy required by the traction motors in a rail car or locomotive in the form demanded by the service, and which automatic method would remove the skill necessary in the operator to obtain the same results by hand manipulation.

My patent No. 1,216,237, issued on February 13, 1927, was for a control intended for an internal-combustion engine using a carbureter, although it also could be used in connection with an oil engine supplied with fuel by a pump. This patent broadly covers an engine-driven speed governor, the range of which would be controlled by the car operator. In other words, by increasing the speed of the engine through the governor control greater horsepower would be developed or less, as the occasion demanded. The speed governor, in its turn, would operate a set of valves acting on a fluid piston, containing either oil or air, and the traveling piston would then first increase the fuel supply to the engine from a minimum to a maximum, while maintaining all the time full field excitation on the generator. Once the full fuel admission is reached, it would then be maintained constant through the rest of the stroke, while the field excitation would be gradually reduced to a minimum.

In other words, between the two extremes of the piston travel somewhere a balance would be found between the fuel furnished to the engine and the field excitation which would give the amount of energy called for by the governor setting in that particular form the service demanded.

My patent No. 1,313,097, issued on August 12, 1919, showed another application of the same principle to an oil-electric locomotive in which, in addition to strengthening and weakening of the field, the grouping of the motors in series and parallel was also automatically performed.

This patent disclosed also a method of controlling the engine speed by the car operator by means of varying the relative speed between the engine crankshaft and the governor, which has the advantage of always utilizing the governor at its most efficient range, which usually runs over about 10 per cent speed variation.

These patents are cited to show the principal reason why, later on, when the time was ripe, I preferred to use what is known as a "drooping characteristic" or "differential control," reference to which has been made by the author.

This method of control, which has found wide application in the United States, in Canada, and abroad, I termed an "inherent automatic control," meaning thereby that it did not depend upon a mechanically directing mind through relays, valves, and contacts and moving members to achieve the results desired, but that the service demands from the traction motor, opposing a separately exciting force, drew automatically a substantial constant energy from the generator over a wide range.

It was never contended that this control would cover exactly the ideal power hyperbola furnished by the engine, but near enough for all practical purposes, and having as its chief advantage great simplicity. All practical railroad men have laid great stress at all times upon as simple equipment possible to give reliability of operation, even if by doing so some of the last 5 or 10 per cent of power utilization had to be sacrified.

The oil-electric locomotives produced jointly by the General Electric, American Locomotive, and Ingersoll-Rand companies have used this "drooping characteristic control" for the past four years successfully, because it is particularly suitable for switching operations, where the accelerations and decelerations are continuously called upon.

I have dreamed that some day the big main-line transportation now done by steam would be supplanted by oil-electric equipment where the great saving of fuel and relatively continuous operation would be brought to its full accomplishment. For this main-line service I anticipated that what is now termed the "speed control," and which is disclosed in the two patents cited, would be employed. As a matter of fact, one of the locomotives now being built at Erie is being so provided.

The graph shown by the author, Fig. 6, is somewhat misleading. In the first place, these curves are developed under the assumption that the engine speed is constant through the whole range, which is not a fact. As soon as the engine tries to unload, its speed will go up. This will take place on both ends of the curve. Hence, the curve *A* is different, and not nearly approaching ideal curve *B*. (See Fig. 11.)

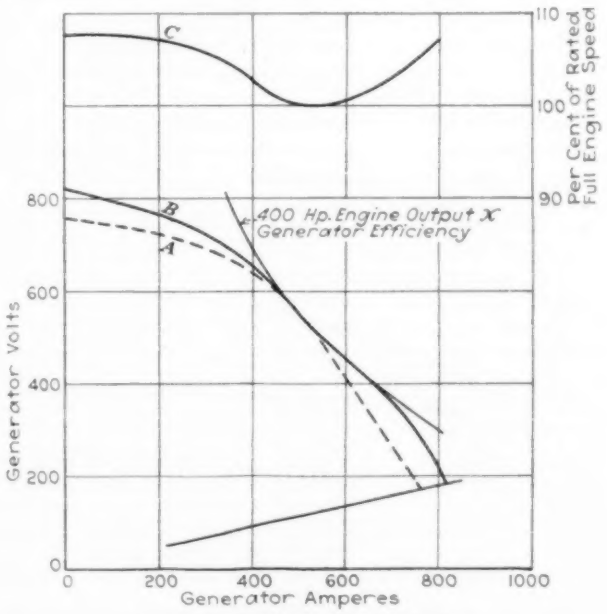


FIG. 11 GENERATOR CHARACTERISTICS

(*A*, test at 100 per cent full engine speed; results on four machines. *B*, test with 400-hp. engine. *C*, per cent rated full speed of engine.)

Second, when the curve *A* is then corrected for the speed variation of the engine, and transferred to the tractive effort curve obtainable with the car or locomotive, it will be found that the variations do not amount to as much as would be implied by the graph diagram of the author. (See Fig. 12.)

Third, when finally a curve is prepared showing the speed variations caused by lack of power, as applied to a car running on

[3] Consulting Engineer, Locomotive Department, Ingersoll-Rand Company, New York, N. Y.

the level and on a grade, it will be found that the maximum variation may amount only to about 5 per cent in the case of the level and less than 2 per cent on a grade. (See Fig. 13.)

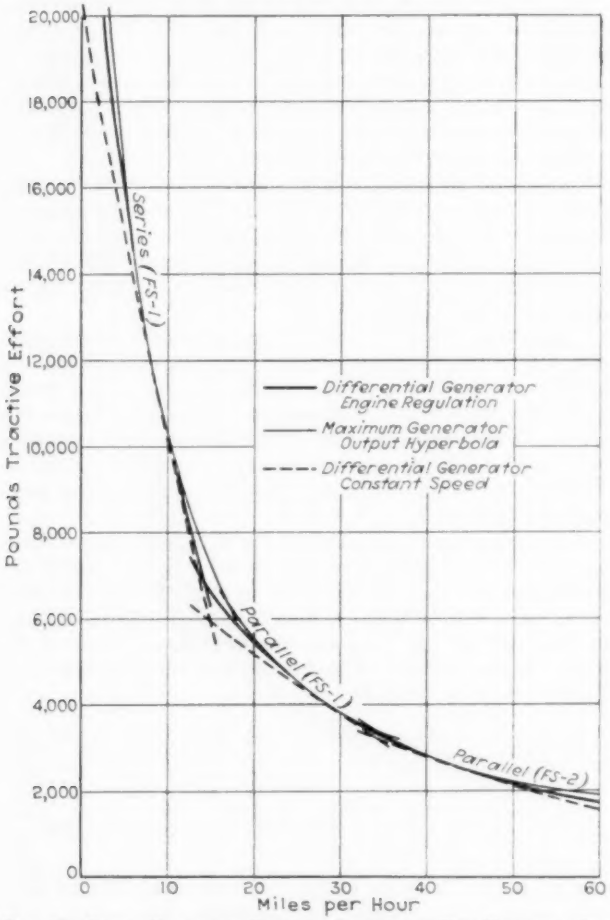


FIG. 12 SPEED-TRACTIVE EFFORT CURVE FOR GAS-ELECTRIC CAR

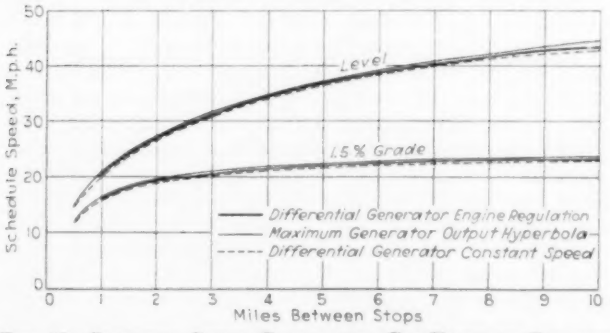


FIG. 13 SCHEDULE SPEED CURVES FOR GAS-ELECTRIC CAR AND TRAILER

(Curves show practical operating schedule speed for continuous operation with normal motor ventilation. Based on 110 per cent of minimum theoretical time in motion without coasting. Duration of stop, 30 sec.; rate of braking, 1.5 m.p.h.p.s.; car friction G E T-3-F; motor car, loaded and equipped, 65 tons; trailer loaded, 50 tons; total train weight, 115 tons.)

Free running speeds	M.p.h.
Maximum output hyperbola, level	57.1
Maximum output hyperbola, 1.5%	25.9
Differential generator engine regulation, level	55.4
Differential generator engine regulation, 1.5%	25.7
Differential generator constant speed, level	54.2
Differential generator constant speed, 1.5%	25.5

Now the question arises if it is necessary to go to the complication of a robot-controlled method with the admitted added complication and possible unreliability, when the inherent control produces only a loss in operating schedule of 5 per cent.

Referring to the author's proposition of using a separate engine set for operating the auxiliaries independent of the main engine, operating the traction motors, the writer is fully in accord with that viewpoint. The General Electric Company used such a unit in their first two-unit locomotive furnished to the Dan Patch Railroad before the war, and in fact used such a unit in most of their rail cars.

With gasoline as a fuel, and particularly with bigger units, this is the right course to pursue. The Brill Company has adopted it. When, however, the same plan is proposed for an oil-electric locomotive, the first cost and the matter of the reliability of a small oil engine for the auxiliaries furnish a real problem.

The General Electric Company has straddled the proposition by using a gasoline engine for the small unit in connection with the traction engine operating on oil, but this is not looked upon favorably by railway officials, because of having to supply two classes of fuel.

However, with the advent of big locomotives, say of 1600 hp., where the auxiliary unit will amount to about 160 hp., such an oil unit is in sight and ought to be used.

F. H. HATCH.[4] The author has presented valuable data on present-day rail-motor-car design technicalities. In a broader sense, however, perhaps a few remarks concerning application and design may not be amiss. Suppose that a given railroad is operating a branch line by steam. Due to competition by bus lines or private automobiles, passenger traffic has fallen off or disappeared altogether; the only reason for operation of the line is mail and express business, or else because abandonment is forbidden by the State authorities. The railroad has decided to give ear to the many claims of economy advanced for the rail motor car and to try one out on this branch line in place of steam passenger service. There are, then, three courses open:

(1) Substitute a small rail car that either is too small or is barely large enough for the service, with the idea that diminution of business is inevitable.

(2) Substitute a single passenger-and-baggage car with sufficient capacity for present-day traffic and with leeway for growth.

(3) Substitute rail-motor equipment of ample capacity for present and future service, but fitted throughout with the latest devices and apparatus for the comfort and convenience of the riding public. Gas-electric drive is arbitrarily assumed.

The first course probably will lead where it is expected to—i.e., ultimate drying up of the service entirely. The second course should hold present business, and if schedules and running times are attractive, might add some seasonal business at least. The third course, provided there are any business potentialities in the territory, should begin, after a short time, to show increasing signs of a traffic comeback.

In the gasoline-electric car, for instance, the gasoline engine is the only part of the equipment that is not electric in its operation and design. Why not definitely set out to make this engine as unnoticeable as possible through the elimination of noise, vibration, fumes, and smoke nuisance, and concentrate on the power plant as a whole to profit fully from the advantages of electrification, including such features as smooth and rapid acceleration, absence of smoke and cinders, quietness of operation, decrease in property damage due to fires started by steam locomotives, etc.? In other words, gas-electric cars (or in fact self-propelled cars in general) have the inherent advantages of electrification which can be realized for branch-line service at costs which are less than for existing steam equipment.

[4] Engineer of Automotive Equipment, N.Y., N.H. & H. R.R. Co., New Haven, Conn.

Such advantages as outlined, together with a superior class of rolling stock, convenient and fast schedules, and reasonable fares, cannot help but attract and hold business in any but the most barren territories. Railroads and manufacturers, in the writer's opinion, would do well to cooperate on their design and application of rail-motor-car equipment, not only that an economical stop-gap for diminishing traffic may be obtained, but that all the latent possibilities for popular and attractive travel may be realized in automotive rolling stock.

So much for the design of the rail motor car as it may relate to attractiveness to the riding public. From the purely railroad viewpoint two features are paramount in the selection of any equipment. These two items are standardization and simplicity. They are important particularly from the maintenance standpoint. A reasonable economy of operation as regards the fuel bill, crew wages, etc., may be entirely wiped out by excessive maintenance.

If all manufacturers had the same ideas or if they should standardize generally in their products, design could properly be left in the hands of such manufacturers, but with the rapid change in the art, coupled with the wide divergence of designs and products on the part of the manufacturers, the railroads are forced to take a hand in design. The ideal solution would seem to lie in cooperation between railroads and manufacturers by means of committees, where free interchange of ideas might take place to the end that rail motor cars could be produced with a reasonable degree of standardization of apparatus and arrangement.

Simplicity is likewise important, particularly where the personnel involved must be trained anew.

Another feature, related to standardization, that is far from helpful to the railroads is the sudden and radical change in design. No management desires to embark on a program of rail motor cars only to find them superseded by other designs before realization on the investment begins. Active cooperation on the part of both railroads and manufacturers should go far to prevent such occurrences.

In conclusion, the rail-motor-car equipment (motor cars and trailers) should be designed as a separate service, which by its very nature can be made attractive to the riding public. At the same time both manufacturers and railroads should cooperate fully on design, to the end that rail-car equipment will prove of greatest use and benefit to the railroad concerned.

In this manner branch-line traffic can be handled in an efficient, economical way and its comforts and attractiveness increased to main-line standards.

O. A. Garber.[5] The problem of rail-motor-car maintenance has been a factor to which every railroad that is operating motor cars has been forced to give serious consideration. Maintenance problems seem more difficult where only a few motor cars are being operated and where frequent changes are made in assignment of cars to operate on divisions where enginemen and mechanics have not become familiar with this type of equipment.

Records indicate that the best performances of motor cars are on divisions where the greatest number of cars are operated or where cars have been operating the greatest length of time.

Many so-called motor-car failures, after investigation, are found to be due to an inexperienced engineman having been called to operate the car or are traceable to an inexperienced mechanic attempting to service the car.

The successful operation of motor cars depends upon three factors—namely: competent and careful operators, proper service and maintenance at terminals, and a suitable repair department with competent and careful mechanics to make general repairs to both mechanical and electrical equipment.

[5] Chief Mechanical Officer, Missouri Pacific Lines, St. Louis, Mo.

A well-designed power plant for rail-motor-car use should endure 200,000 miles of service before renewal of bearings or general repair becomes necessary. The best performance is secured from motor cars that are assigned to trains making from 250 to 350 miles per day.

To maintain and service motor cars requires the skill of a good mechanic. At each terminal where motor cars lay over, a competent mechanic accustomed to close tolerance should be selected for the work.

A form indicating stated periods when service of the various kinds is to be performed, such as oiling, cleaning, adjusting, etc., of the various appliances, should be kept for each car, which will assist in securing regular service and provide a means for supervisors to check work performed. Enginemen or motor-car operators should be required to give a general inspection of all mechanical and electrical equipment at the end of the run, and they should indicate on a suitable work-report form any defects noted and also any unusual performance.

When renewal of broken or worn parts becomes necessary, they should be replaced in kind, so that service parts will always be interchangeable. Emergency makeshift repairs should always be corrected promptly.

In designing power-plant equipment for rail motor cars, manufacturers can assist in reducing maintenance costs materially by giving consideration to accessibility and simplicity as well as to stability.

In power plants of 200 hp. and above operating on gasoline or distillate the engine-cooling system presents a problem for careful study. Circulating a maximum quantity of water through the cooling system in a given time does not always accomplish the desired results. Slime and mud will frequently accumulate in the water passages of cylinder heads and cylinder water boxes or jackets and are difficult to remove unless a plug or a removable plate is provided at the bottom section of water passages for occasional flushing or washing out.

Various types of radiators have been developed, but much has yet to be accomplished in providing a radiator that will withstand the severe stress and strain encountered in rail-motor-car service.

The importance of the engine-cooling system can be more readily understood when considering the fact that the limited dissipation of heat through the cooling system has made it very difficult to develop and operate engines of greater than 450 to 500 hp. successfully with gasoline or distillate fuel.

Proper lubrication is also a vital factor, and it does seem that much would be gained if the circulating oil could be filtered and be maintained at lower temperatures through some method of cooling.

The development of rail motor cars is advancing very rapidly, and any attempt toward standardization at this stage of development may retard progress.

The writer feels that, with the cooperation between the railroads and the manufacturers, the rail motor car will soon be developed to a point of efficiency and in sizes suitable to handle almost any class of service.

W. J. Wilson.[6] These comments are offered by the Union Pacific as an addition to some details of the paper and not in disagreement thereto.

(1) While generally true that the rail car was not accepted as an important unit of transportation until recently, there are some exceptions, such as for example the Union Pacific System, upon which rail-car service was started in 1905 with the first McKeen-type car. Thirty-two of these cars are still in service, all of them over 15 years old and several over 20 years; the latter having

[6] Charge of Rail-Motor-Car Design, Union Pacific System, Omaha, Neb.

considerably more than a million miles of service to their credit. Twenty-three gas-electrics have been added in recent years, making a total of 55 cars in service, which number will be increased progressively.

(2) It is desirable from the manufacturer's viewpoint to adhere to a standard or predesigned car in so far as possible. Operating conditions, fixed policies or programs, and ideas based on experience vary to such an extent that some flexibility is necessary in any design. (Some changes usually are required when distillate is used.)

(3) The Union Pacific is in full accord with all efforts to eliminate unnecessary weight, having persistently advocated and practiced such a policy for years. In the semitubular structure of the McKeen car body great strength was attained with the use of a relatively small amount of material.

(4) In connection with depreciation, the Union Pacific makes no distinction between the car body and power apparatus. The experience with the McKeen car seems to justify this policy. (The Union Pacific depreciation rate is $4^1/_2$ per cent.)

(5) Relative to the use of distillate as fuel, the Union Pacific believes that it competes in practically all respects with gasoline, except in first cost of equipment, which is approximately $1200 more, and in ease of handling. These conclusions are based on 15 years' experience with this fuel, during which time a number of gasoline cars also have been used for limited periods. A certain skill, easily acquired, is necessary on the part of operators for best operation with distillate fuel. So far as we are able to determine no more servicing is required than with gasoline and repair bills are no higher. The distillate used by the Union Pacific has an end-point of about 620 deg. and is considered only a medium-grade fuel. Higher grades are available in large quantities in some districts. (The average price of distillate in 1928 was $4^3/_4$ cents. The average price of gasoline in 1928 was $9^1/_4$ cents. The gasoline tax of 3 and 4 cents applied to rail cars.)

(6) No systematic tests to develop comparative output of distillate and gasoline cars have been made, but actual service indicates a superior performance with distillate. The low resistance of the short gas path through the distillate carbureters makes the volumetric efficiency high, which offsets the effect of lower compression.

(7) Proper cooling of exhaust valves is vital, but less trouble is experienced with valves in distillate engines than in gasoline. The water used for detonation control reduces the temperature of the valves and checks carbon deposits. The distillate also provides top lubrication. Grinding valves is an infrequent operation.

(8) The combustion chamber design presented appears well suited to distillate fuel, and it is believed that a higher compression may be feasible. (The compression for distillate is now 65 to 70 lb.)

(9) Dowels and screws are ineffective for retaining bearing shells in engine beds or bearing boxes. The cap described by the author should hold them securely and prove satisfactory, provided there is no difficulty in the application of babbitt direct to the steel cap.

(10) For use in distillate engines it is advantageous to cool the lubricating oil as much as practicable to improve the operating viscosity. But little distillate dilution can be boiled off at the usual operating temperatures, this dilution being composed of heavy ends requiring high temperatures for evaporation. Crankcase ventilation is effective for removal of vapors which otherwise might condense.

(11) Electrically driven rotary fuel pumps, one for each kind of fuel, have proved very satisfactory on the Union Pacific. Fuel is delivered to the engine at a constant rate, that in excess of the requirements overflowing back to the tanks. No floats or float valves are used in the carbureters.

(12) The small auxiliary engine described would make an undesirable increase in the gasoline consumption of a distillate car. It would no doubt be feasible, however, to arrange for the use of distillate on this small unit.

Author's Closure

Referring first to Mr. Lemp's contribution, the author makes no claim for the discovery of the speed-control principle nor does he mean in any way to imply that the speed-control principle cannot be worked out satisfactorily by methods other than that used. He was not previously aware of the patents issued to Mr. Lemp, to which reference was made, but through the courtesy of Mr. Lemp has been supplied with copies of the patents cited, explaining his method of speed control. Other satisfactory methods have been developed by Mr. McNary of the General Electric Company and by the engineers of the Westinghouse Electric & Manufacturing Company, these being embodied in their so-called "engine torque control." Mr. Lemp's objections to speed control as originally proposed—i.e., the undesirability of relays, valves, contacts, etc.—are of course valid. Since the control described in the subject article avoids the use of such apparatus, however, and is a very simple and entirely straightforward mechanical device, involving no new principles and no added complications, it is felt that these objections have now been eliminated. Mr. Lemp dwells at some length upon the fact that by using a "broad tuning" governor the differentially controlled generator will more nearly approximate the engine-horsepower hyperbola than is indicated in the author's sketches. This is quite true. If, on the other hand, it is considered permissible to operate the engine at these higher speeds and if, then, the speed control is set for such higher speeds, the advantage of utilization is in favor of the speed control; or if, for example, the differential-control equipment and its governor are so set that the average speed is equivalent to the speed when using speed control, then again the advantage is in favor of the latter device. If, therefore, any predetermined speed is considered as the correct speed for the engine—no matter what that particular speed may be, whether high or low—improved performance will be obtained with the speed control. The author has found in calculating numerous applications that the gain is usually about 5 per cent.

Mr. Hatch's suggestion as to cooperation between the manufacturers and users of rail cars is, of course, quite right. The manufacturers are desirous of building the best equipment they can to meet general conditions, and inasmuch as there is a general trend in experience which can be embodied in new designs, it can and should be followed. Due to the tremendous development expense which the manufacturer must undertake for his own account, however, it is not desirable or expedient to make detail modifications of an established design to meet the wishes of a particular customer, if it can possibly be avoided—this for the reason that manufacturing such special parts in relatively small quantities as might be required by any particular purchaser and conducting the necessary tests in connection with such special developments will run the cost out of all comparison to a standardized product. Further, the manufacturer can, in some cases, by reason of experience gained on numerous properties, better judge as to what should be done than might be possible from the limited experience of any one operator. The manufacturer can of course draw on experience under all sorts of operating conditions and incorporate the results of such experience with his standard designs.

There is no question as to the undesirability of sudden changes in design, from the standpoint of users. On the other hand, the modern rail motor car as at present built is still comparatively new, and it would seem that for the best interests of all concerned

such changes as are necessary as a result of experience should be made from time to time.

Mr. Hatch also raises one other question, with which the manufacturers are heartily in accord. The rail motor car cannot realize its full potentialities until it is considered on its own merits and applied to its own best advantage, rather than merely being considered as a substitute for the steam locomotive. If the advantages peculiar to the rail motor car are given due consideration in its application, it should, as Mr. Hatch points out, make a very definite niche for itself. Some of the points which should be considered are (1) possibility of light trains with more frequent service, (2) lighter weight car design by reason of the lighter trains, (3) freedom from smoke, cinders, etc., (4) smooth acceleration, and (5) the reduced stand-by losses.

Mr. Garber has touched a very fundamental question in connection with the operation and maintenance of rail motor cars, and his experience coincides with that of other operators, particularly in the following points:

Cars operating moderately long mileage will give best results. Maintenance must be in the hands of a mechanic accustomed to work of the required character. If possible, a particular man should be responsible for the condition of any given car or lot of cars. A definite inspection, maintenance, and adjustment schedule should be established and rigidly adhered to. A competent supervisor should be appointed, having complete charge of all cars on a system.

The accumulation of impurities in the water-circulating system is particularly injurious if a heavy coating of scale is deposited on the cylinder liners and in the cylinder heads. It is necessary that adequate steps be taken to insure that such accumulations are removed before they become heavy enough to cause damage by reason of the lessened heat flow.

Regarding the cooling radiators, it is felt that the modern fan-cooled, roof-type radiator, as developed about four years ago, should give entirely satisfactory service.

In regard to the matter of oil filtration, the author has had entirely satisfactory results with oil filters built into the car, incorporating a series of felt washers under compression, through which the oil is filtered. These have been used as standard equipment for the past several years and should meet Mr. Garber's suggestion.

The author also has found it desirable to maintain the lubricating oil at approximately the same temperature as the cooling water. Running the oil too cool is very undesirable, as it permits higher dilution. On the other hand, the oil must be held at a temperature low enough to prevent oxidation. A temperature of 140 to 170 deg. fahr. has been found quite satisfactory.

It is noted that Mr. Wilson feels the oil temperature should be held somewhat lower, and it is of course possible that when using the heavier fuel conditions may vary.

The rotary fuel pumps to which Mr. Wilson makes reference have been found quite satisfactory on distillate, but it seems doubtful whether their life would be satisfactory when operating continuously on gasoline, due to the absence of lubricating qualities in the gasoline itself.

Symposium on the Maintenance of Rail Motor Cars

Gas Rail Cars on the New Haven Railroad

By E. O. WHITFIELD,[1] NEW HAVEN, CONN.

THIS paper outlines various rail-car problems, pertaining particularly to organization and maintenance, that have been dealt with on the New Haven railroad over a period of approximately eight years. As would naturally be expected, a vast amount of pioneer work has been necessary to bring rail-car internal-combustion and transmission equipment up to its present state of efficiency and reliability.

Brief History

The New Haven railroad today operates 36 rail cars, which vary in life from 2½ to 8 years. Their description is as follows:

No.	Type of car	Age, years	Transmission	Pass. cap.	Engine hp.
3	Mack (9000–02)	8	Mechanical	35	45 at 1200 r.p.m.
1	Wby. hydraulic (9003)	6	Hydraulic	65	160 at 1200 r.p.m.
10	Sykes (9004–13)	5	Mechanical	45	130 at 1600 r.p.m.
10	Brill No. 65 (9014–23)	4½	Mechanical	50	130 at 1600 r.p.m.
12	Brill gas-electric (9100–11)	2½ 3½	Electrical	90	250 at 1100 r.p.m.

Twenty-three of these cars are mechanical drive, one hydraulic transmission, and twelve gas-electric.

It may be noticed from the foregoing that progress in design and size of equipment was rapid, although cars 9004–23 and 9100–11 represent a group of 32 units of definite standards and characteristics.

Organization

Although the New Haven made its "debut" in the gas rail-car field as far back as 1922, it was not until 1925 that a separate maintenance organization was created to specialize on gas rail-car operation. The present automotive maintenance organization consists of a supervisor of rail car maintenance and inspection, reporting direct to the general mechanical superintendent and five specially qualified rail-car inspectors, reporting to the supervisor. The automotive division, as it is called, supervises the entire maintenance program at the outside terminals, also at the main repair shop at New Haven. It was found necessary to create a separate organization, especially in view of the scattered assignment of cars and the necessity for segregating upkeep and other work from steam, as this new work presented many differing problems entirely new to the railroad. The rail-car inspectors qualify operators, inspect cars, instruct and examine maintainers, assist in emergency repairs and trouble shooting, and also take care of general matters pertaining to rail-car maintenance. They must be on hand to assist at any time they may be called upon. An engineer of automotive equipment reports to the mechanical engineer and follows through all engineering revisions, cooperating with the supervisor of rail-car maintenance and inspection in the elimination of design failures. Specifications pertaining to new equipment come under the engineering department for preparation. With the construction of a separate organization, serviceability has improved.

Maintenance

(1) *Decentralization.* On the New Haven the rail-car assignments are scattered, terminals in many cases being at most inaccessible points, which immediately brought up difficult problems, especially regarding maintenance and inspection. The assignment of cars includes Poughkeepsie on the west, Chatham on the east, and Fitchburg and Pittsfield on the north, the territory being bounded by the shore line on the south and with many scattered assignments coming in between.

(2) *Divisional Separation.* In former days, inasmuch as the entire system was operated with steam, it was only necessary to carve up the operating territory into several divisions and assign master mechanics to each portion, who would in turn each have his group of terminals, foremen, and maintainers to take care of. When the rail cars were assigned to their different runs, it frequently occurred that several cars within a radius of a few miles would come under the jurisdiction of several master mechanics. This in turn meant a different group of maintainers for each car, with decentralized control and responsibility.

(3) *Grouped Maintenance.* We have settled on the following principles, which are working satisfactorily. At points where it is possible to bring a group of cars under fully qualified maintainers, it has been the practice to so handle them, even though, as stated, cars operate on two or three different divisions. The result is, therefore, that a group of cars comes under competent and trained mechanics and under one master mechanic, who is responsible for the entire group, such a group of cars being covered by a rail-car inspector at least weekly. At points where it is impossible to group cars it is sometimes found the best and most economical method to assign a mechanic to perhaps only one car. In order to demonstrate this feature, suppose we arrange to maintain an isolated car by intermittent attention from some central point. The time taken going to and from the car is the largest single item of labor, and there is actually little time left for maintenance, and it is found eventually that overtime has to be resorted to in such cases, with incident expenses. Therefore, it has been found desirable to locate a mechanic at points where, due to their inaccessibility, they cannot be reached promptly from a major repair terminal. Cars coming into large terminals present little difficulty from a maintenance standpoint and are assigned certain hours with a fully qualified maintainer.

(4) *Instruction and Education of Maintainers.* One of the chief duties of the rail-car inspectors is to instruct and educate maintainers and to train them to be sufficiently exacting to properly take care of equipment under their charge so that they may by daily check preclude possibility of failure due to defective conditions. Inspectors are therefore instructed to work entire shifts with maintainers, going through each item on the maintenance card. The inspector is called upon to fill out a form, indicating the efficiency of the maintainer in the various branches, such as trouble shooting, card reports, questionnaires, operation, intelligence, and average efficiency rating. In addition to this education, the maintainer is provided with instruction books and also questionnaires covering equipment under his care. In connection with maintenance on gas-electric cars, it is expected that the mechanic in charge will be capable of taking care of both the mechanical and electrical details satisfactorily without its being necessary to divide responsibility, and he is educated on this basis.

(5) *Maintainers' Records.* The maintainer is required to fill in a maintenance card which covers daily, weekly, semi-monthly, and monthly maintenance items for every unit on the cars he is called upon to maintain. This is sent into the master mechanic at the end of the month for signature and then to the supervisor. The inspector's card is filled out weekly covering every car under his jurisdiction, which is also forwarded to the supervisor at the end of the week. The inspector on his weekly visits writes up a report to the maintainer covering defects noted, which are checked again the following week. Fuel and lubrication cards

[1] Supervisor of Rail-Car Maintenance and Inspection, New York, New Haven & Hartford Railroad.

indicate gasoline used on various cars together with the amount of grease, oil, and transmission lubricant, specifying also the brand. These are signed by the master mechanics and sent to the supervisor at the end of each month. Cards also are kept on the condition of batteries, and it is expected that the maintainer will make a report on the gravity reading of each cell daily, sending such a card to the supervisor at the end of each month. The inspector also takes hydrometer readings in his weekly visits. The maintenance and fuel-lubrication cards are kept in a sheet-metal case hanging on the wall of the engine room in order that they may be referred to by the supervisor or inspector at any time, thereby telling at a glance whether maintenance work is being properly taken care of and as prescribed by the management.

Qualification of Operators

Each prospective operator must be instructed by a rail-car inspector and is issued a qualification card, signed by the master mechanic and inspector in charge. Engineers are also instructed in minor trouble shooting. Requirements under this heading are strict, and under no condition is an operator provided with a certificate until he is fully familiar with his duties.

Facilities

The matter of providing adequate facilities broached a difficult program in view of the fact that assignments were frequently changed, but it is sufficient to state that concrete floors are desirable, together with proper greasing and oiling facilities, with material supplies, and correct assortment of tools and wrenches to suit the equipment. Such items as proper capacity-delivery gas pumps and strainers reduce troubles due to the fuel system. Proper provision for the keeping and the segregation of lubricants should be made in order that they may be kept clean and free from grit and foreign matter. The correct brand of lubricant should also be specified. The foregoing touches on facilities at the outside points, but does not cover major shops such as New Haven.

Main Shop

The railroad carries out its major repairs at the New Haven shop. This shop is equipped to take care of both large and small cars and has the proper tools for fitting main and rod bearings accurately, together with engine dynamometer, water rheostat, electrical-instrument and auxiliary testing apparatus, special fuel-system testing benches, etc. All work that passes through the New Haven shop must be passed on by a competent resident inspector, who fills out a report form on every car released from the shop.

Cars are scheduled through the shop to conform with the units available for application to the car such as engines, trucks, air compressors, and transmissions. Although engines are tested on dynamometer before being placed in the car, the completed unit is taken out finally on a standard test run, which includes severe grades and curvature, sufficient to give the car a thorough trial. Each of these test runs is in charge of the resident inspector, who takes note of defects and reports them to the superintendent for attention. On completion of the repairs the work is again inspected. Numerous tools have been developed to take care of this highly specialized work, but when the work of general overhaul on the large sizes of engines was commenced (250 hp.) there was nothing on the market to meet requirements, and it was necessary for our tool designers and shop forces to build up suitable boring bars, special reamers, and fixtures to carry out this work, in addition to special testing apparatus for testing vacuum tanks, oil pumps, vacuum pumps, tachometers, carburetors, etc.

Unit Replacement Program

As far as is possible with the regular scheduling of cars, units are brought into the shop to conform with the unit replacement program. For instance, if it is desired to bring in a mechanical car from the outside, we make sure that complete assemblies, such as engine, transmission, and trucks, are ready, so that when the car arrives at the shop it is stripped of its equipment and the new replacement items are installed. We have acquired spare engines for our gas-electrics, also spare trucks, generators, and motors, and as a consequence have been able to reduce the shipping period of these cars one-half. When one considers that whenever a gas-electric car is taken out of service, generally speaking, it is replaced by steam, it can readily be seen that it is poor economy to keep a car in the shops. Therefore, a little capital spent on spare units is very quickly repaid.

It is important to remember that whenever new facilities are considered, ample room should be available with overhead cranes, well-constructed pits and floors of concrete, together with best possible lighting and heating facilities. As far as the tool and testing apparatus goes, it should be the best procurable in order to provide for the extreme accuracy which is required in automotive work, especially on large power where continuity of service is paramount.

Statistics, Records, Charts

When an attempt was made to build up the first rail-car organization, it was found that records covering the service of cars were meager and practically useless. In order, therefore, to handle the matter in a logical way and give foundation to a proper organization, it was necessary to have complete statistics available so that trend and direction might be noted and pressure brought to bear on weak points. Charts and statistics cover shopping periods, car miles per failure, per cent of serviceable days, failures per month, car-shop days, maintenance costs, labor and material, such information being divided between lines east and west. If weak spots are to be found, it is necessary that full and complete charts be ready for quick reference in order that concentration may be brought to bear upon any particular item of design, maintenance, or inspection needing attention.

To Organize Is to Economize

With the proper rail-car organization and trained maintenance forces available, there will be ample opportunity to expect economies over steam service on a large number of assignments, to say nothing of the possibilities of supplementing and effectively handling main-line service.

At the time this paper was completed the serviceability for the month on all cars was over 90 per cent, and lines west forces, operating 14 rail cars (5 gas-electric and 9 mechanical), operated three consecutive months without a single road delay of five minutes or over. An improvement of 36 per cent was noted for the first half of 1929 over 1928 in reduction of road delays, and 23 mechanical gear-shift cars operated the entire month 31,349 miles without a delay. If this may be considered good performance, it is the result of a carefully built-up program of maintenance and inspection with a separate organization in charge.

The following views illustrate the method of operation:

Fig. 1 shows the New Haven rail-car organization, supervisor reporting to the general mechanical superintendent, and five specially qualified rail car inspectors reporting to the supervisor. Engineer of automotive equipment reports to the mechanical engineer and cooperates directly with the maintenance and inspection forces toward the betterment of operation in matters pertaining to design.

Fig. 2 shows the location of rail cars on the New Haven

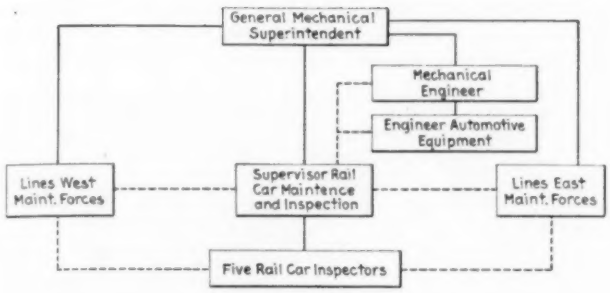


FIG. 1

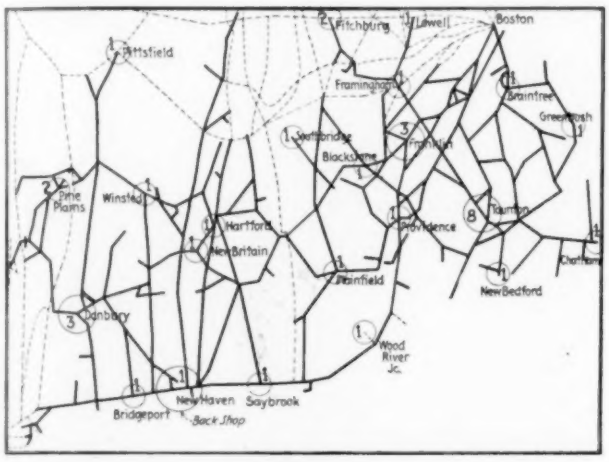


FIG. 2

system. There are 36 of these units, 23 with mechanical drive, 10 gas-electric, and 1 with hydraulic transmission. The cars are scattered over the operating territory, making maintenance difficult.

Fig. 3 shows the failures per car per month for the last five years and indicates the trend due to concentration on organization and maintenance items which have made for greater efficiency. It also shows the number of car-shop days per car per month, also indicating a downward trend toward greater efficiency and serviceability.

Fig. 4 shows the distribution of failures divided between drive, engine, auxiliary, and gas system. This chart was primarily made up to distribute failures between engine, drive, and gas system, as there was considerable difficulty with fuel systems. Fuel system failures for the past months have been zero, largely due to the installation of a fuel system of fuel supply.

Fig. 5 shows a Brill mechanical car having drive truck removed. The body is being raised by a Whiting electric hoist.

Fig. 6 shows the cleaning tank. After the engines are dismantled they are washed in a tank which uses an Oakite solution prepared for use with aluminum. The unit being removed from the tank is a crankcase from a 250-hp. engine. The steam nozzle at side of tank is used in the final operation after the parts are cleansed in the tank. This tank has a depth of 2 ft. below the surface of the concrete.

Fig. 7 shows the connecting rod from a 250-hp. engine having faces squared by means of fly cutter. The arbor exactly fits the bearing. This machine is also used for boring out rod bearings.

Fig. 8 shows a Sterling Seagull engine undergoing oil-pressure

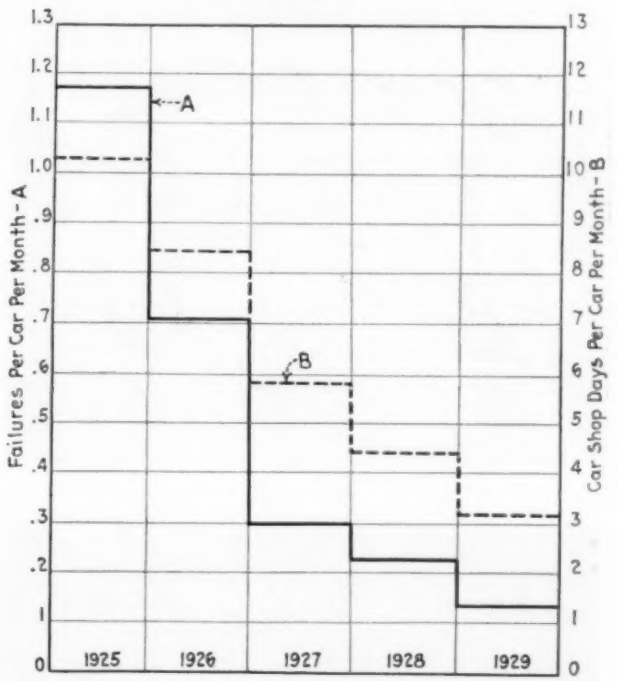


FIG. 3

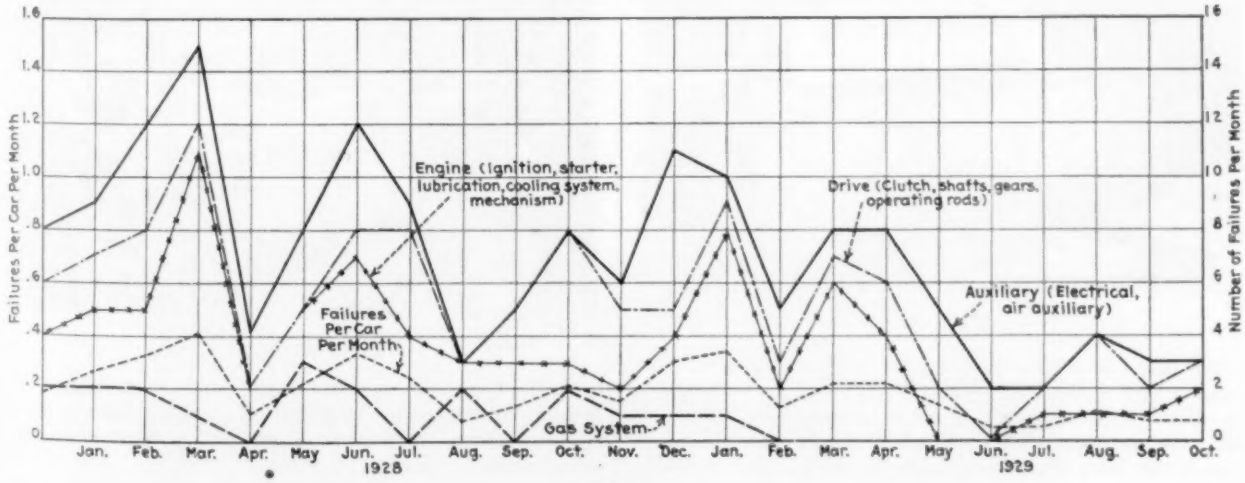


FIG. 4

test when rebuilt. The oil tank, with air-pipe attachment, is connected to the ingoing oil-lead pressure being shown up on the gage. The test shows up faulty piping, connections, and bearing fits.

Fig. 9 shows fuel and auxiliary testing apparatus. Especially

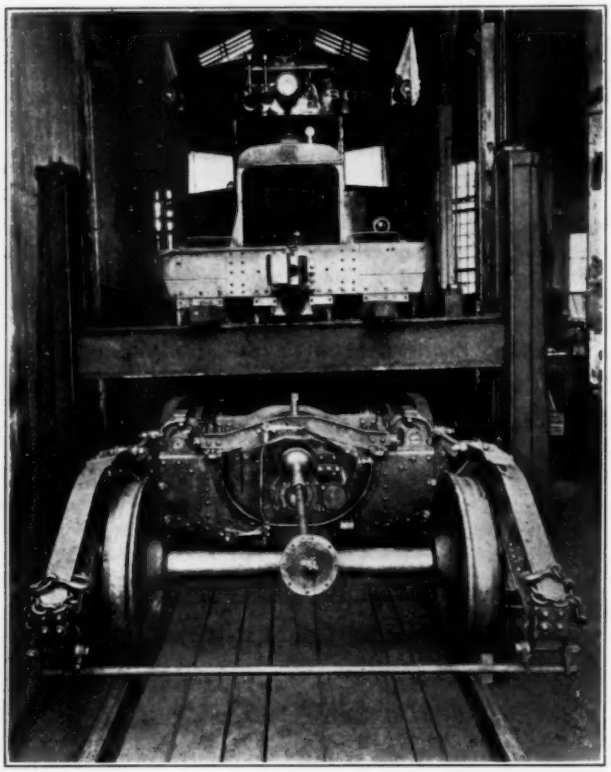


FIG. 5

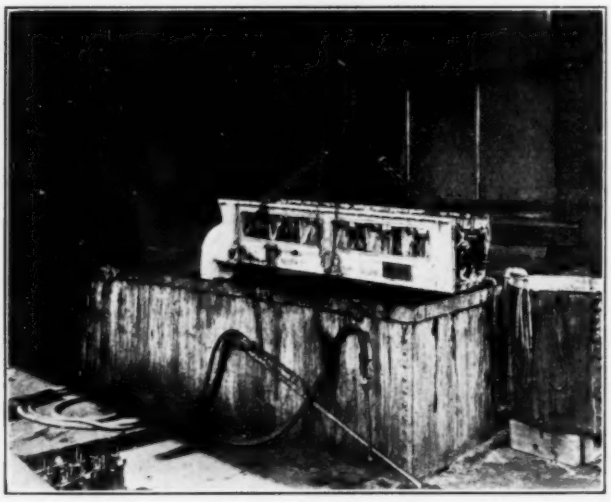


FIG. 6

is this bench used for testing vacuum tanks and pumps. The mercury tube in the center provides a yardstick for determining vacuum. At the right are two water columns for testing inner tanks for air leaks. When the tanks are air-tight, the water columns are level, but when air leaks are shown, the indications are that the tank is faulty. The tank is then removed, and a few drops of gasoline are poured into tank, which is then placed in a bucket of hot water. The gas, vaporizing quickly under the heat, will leak through and show up the location of the de-

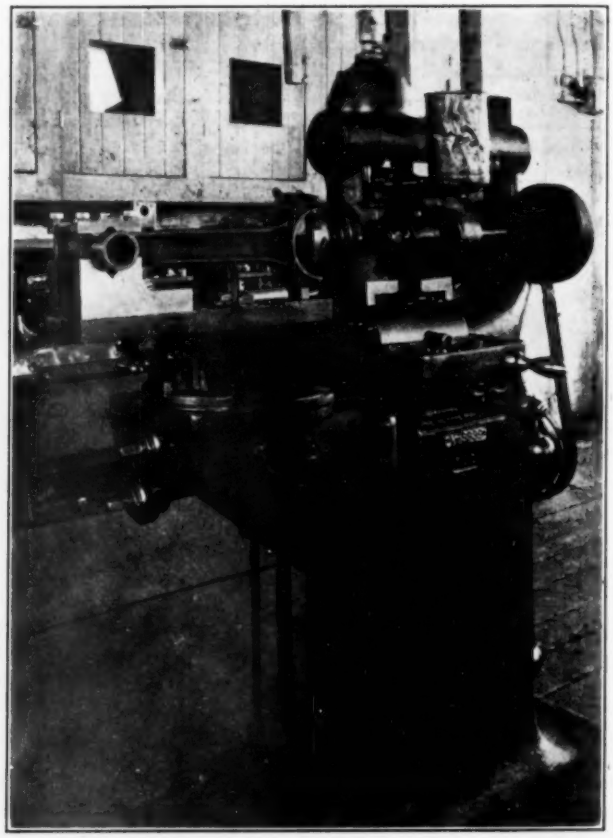


FIG. 7

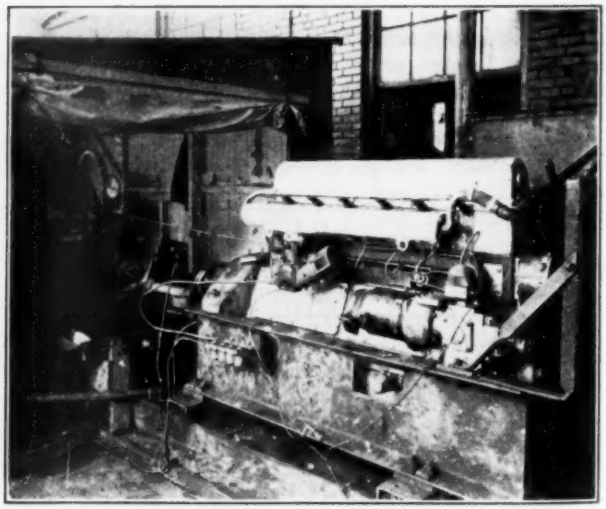


FIG. 8

fect. Tachometers, mercury gages, oil-pressure gages, carburetors, and oil pumps are tested out on this apparatus, which is friction-driven for variable speeds. On the left is shown a valve grinder of conventional type.

Fig. 10 shows a gas-electric car undergoing electrical test,



FIG. 9

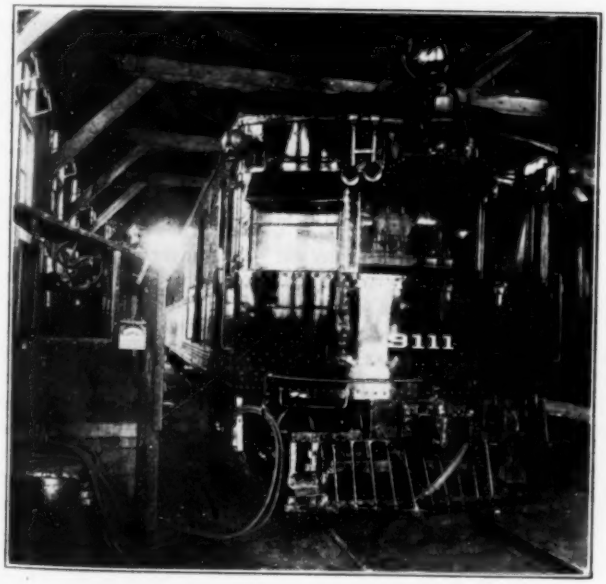


FIG. 10



FIG. 11



FIG. 12

a water rheostat being used. The hand wheel is used to increase and decrease electrical resistance. By using a water rheostat, exact electrical settings can be obtained to conform with the manufacturer's recommendations.

Fig. 11 shows one of the original Mack cars of eight years ago alongside a recent gas-electric.

Fig. 12 is a longitudinal view of a Mack and a recent gas-electric car, giving a comparison as to the progress made in the last six or eight years.

Rail Cars on the Union Pacific System

By W. J. WILSON,[1] OMAHA, NEB.

ORDINARY running repairs and servicing operations to Union Pacific rail cars are performed at layover terminals, where also occasional heavy emergency repairs are made to some parts of the car.

Cars are overhauled regularly on a predetermined mileage schedule of approximately 110,000 for the McKeen-type mechanical-drive cars and 120,000 miles for the gas-electric type. This work is done at the principal shops of each railroad of the system, where are maintained a personnel and an equipment for that specialized work. The overhauls are thorough, both for the power plant and the car body. Cars are maintained to as nearly as possible as new condition, and since improvements are added frequently, cars a few years old operate more perfectly than when new.

An example of this servicing policy is seen in the McKeen cars, of which there are still 32 in operation in the Union Pacific System, all old cars, some them over 20 years. Due to the elimination of all weak points, their cars are more economical and reliable than when first constructed.

Improvements to cars and servicing equipment are developed by those interested, usually through collaboration of the automotive section of the engineering department, the motor car supervisor and shop groups.

Some individual details of rail cars in which troubles have been met and overcome and special phases in connection with maintenance will be described.

Crankshafts and Bearings

Little trouble is experienced with crankshafts, but some is had with main and rod bearings.

These in the McKeen-type engines are of solid bronze and occasionally overheat. The construction of these engines permits application of a water stream which keeps them sufficiently cool to reach a terminal where proper attention may be given.

Difficulties with gas-electrics are varied, but are usually the result of some lubrication defect. It is noticed that this occurs with an engine having relatively small bearings, and that another with liberal bearings and counterbalanced shaft is trouble-free.

Dowels and screws do not hold bearing shells tight into the boxes, and improvement results by providing heavy shims, extending around the bolts and nearly into contact with the shaft. When caps are in place, these hold the bearings securely. Caps should be doweled or dovetailed to keep the alignment perfect. Crankshafts are refinished when worn appreciably out of round, those of the McKeen engines being turned with a special crankshaft tool and those of the gas-electric engines being reground. Hand fitting of bearings is unsatisfactory, as it is practically impossible to get both a perfect fit and alignment. This practice has been discontinued.

Main bearings are now fitted with a special reamer bar having both cutting and burnishing blades, except in the case of the McKeen bronze bearings, for which a special line-boring machine is being constructed.

Rod bearings are fitted with a combined aligning, reaming, and burnishing fixture.

Cylinder Heads

Valves and sets give little trouble, regrinding is infrequent, and but little carbon is deposited in the distillate-burning engines, this being attributed to the use of water for control of detonation.

The only trouble encountered consists of cracking between valves, which trouble is corrected by providing unrestricted water circulation through all parts of the head, particularly between the valves, and by the elimination of steam pockets and unwatered areas. Replacement heads designed to the railroad company's specifications are now being made for such engines as require them. Replacement seats and equipment for application are available at low cost, but have not as yet been required.

Pistons and Cylinder Sleeves

Aluminum-alloy pistons are generally superior to cast iron, both in service rendered and effect on other parts of the engine. A 10-in. diameter split-skirt type applied to the McKeen engine, while costing more than cast iron, reduces the effective load on the main bearings and assists in control of detonation by a reduction of the hot area at the center of the piston head.

A plain type alloy piston with a solid skirt and but little ribbing is used in the gas-electric engines. These are purchased at a price lower than patented split-skirt types, and the service obtained is satisfactory. The first set applied more than a year ago is still in service, so no definite mileage is as yet established.

New pistons are usually purchased about 0.060 in. oversize to permit of successive refitting to smaller sizes. Reground or new sleeves are provided to fit. This reversal of the usual automotive practice is economical because of the greater value of pistons as compared to sleeves. New sleeves are manufactured in the railroad company's shops.

Floating wristpins are used in one type of gas-electric engine and in the aluminum pistons of the McKeen engines. The latter have no wristpin retainers, but have an alloy thrust block in the end of the pin, which prevents scoring of the cylinder walls.

Pistons are fitted with a clearance of 0.0015 in. per inch of diameter at the skirt, with an increased amount at the ring lands and top.

Ordinary cast-iron rings have given poor service on distillate engines. Narrow steel rings, two $^5/_{32}$ in. wide in one $^5/_{16}$-in. groove and "Double seal" type rings have proved satisfactory. Both types give a tight seal and have a wide bearing on the ring lands.

Ordinarily rings are fitted with 0.015 to 0.018-in. gap, a similar clearance back of ring, and 0.002 to 0.003-in. groove clearance.

Little trouble has been experienced with the rubber seal rings of the cylinder sleeves or with electrolytic action pitting the outer surfaces of the sleeves.

Lubricating Systems

Some lubricating pumps have a short service life. Rapid wear of small bearings develops excessive internal clearance and results in loss of pressure. A redesign of the pump is the only solution apparent.

Relief valves and seats are subject to rapid wear, and in some instances external reliefs have been applied in the pipe lines.

Oil-distribution manifolds cast into bedplates have accounted

[1] Charge of Rail Motor Car Design, Union Pacific System.

for some car failures. These are removed as engines are shopped, and an external manifold is applied.

Felt cartridge-type oil filters are of value even with the frequently changed clean oil of distillate engines. These are being applied to engines not originally so equipped.

Ignition Apparatus

Since no ignition apparatus wholly satisfactory for rail-car use seems to be available, it follows that considerable attention must be given to keep this apparatus working properly and the duplicate units synchronized.

Magnetos and distributors are serviced frequently, and wiring is replaced to prevent electrical loss through oil-soaked insulation. Insulation coverings which resist oil penetration are preferred. Mallory coils are used on battery ignition systems in place of those originally supplied.

Exhaust Pipes

Earlier designs of exhaust pipes for gas-electric cars consisted of built-up cast- and wrought-steel manifolds, pipes, and mufflers. These were quickly destroyed by the hot exhaust gases and required frequent renewal.

Pipes now used are a special Union Pacific design entirely of cast iron, are of large diameter, and are thin walled. Three pipes are used on a six-cylinder engine, each surmounted by a cast-iron exhaust head to subdue the sharp report of the exhaust. These pipes are of relative light weight and long life, create but little back pressure, and are reasonably quiet.

Pipes on the McKeen cars consists of two light sheet-metal tubes projecting through the roof of car and are connected one to each three cylinders with a cast manifold. No mufflers are used.

Carburetors and Fuel Systems

Maintenance of the distillate carburetors in service consists principally of keeping fuel-line connections tight.

At shopping periods the carburetors are serviced by the manufacturer of the equipment, and all parts are restored to the condition of new.

Little trouble is experienced with stopping up of the small multiple fuel jets, as large strainers and water separators are used on the fuel lines.

Pressure-fuel feed from tanks function satisfactorily, but presents a hazard in case of fire in the engine room.

Such vacuum systems as were tried proved unreliable and were discarded. Where electric energy is available, the most satisfactory system is electrically driven pumps, one being provided for each fuel used. These consist of rotary pumps of the "Viking" type, direct-connected to $^1/_8$-hp. motors. Fuel is delivered at a fixed rate to the chambers on the carburetors, and the excess over engine requirements overflows back to the tanks. All floats and valves are eliminated, and no fuel is stored in the engine room.

Cooling Systems

Radiators of the cellular and flat-tube type become clogged with lime and loose scale where water conditions are bad. For this reason radiators using large diameter tubes are favored. However, cooling systems are now washed out periodically with cleaning compound, which has overcome these difficulties. Where aluminum is used in the cooling circuit, chemicals which attack that metal must be avoided.

Roof radiators are favored, since freezing is eliminated, because they contain no water during idle periods.

Connecting radiator units in multiple rather than in series is favored on account of freer circulation and resultant increase of water flow from the pump.

Motor-Armature and Suspension Bearings

Occasional replacement of motor-armature and suspension bearings is necessary.

Satisfactory results are realized in the case of armature bearings only when the new bearings are assembled to the motor frame and line-bored or reamed.

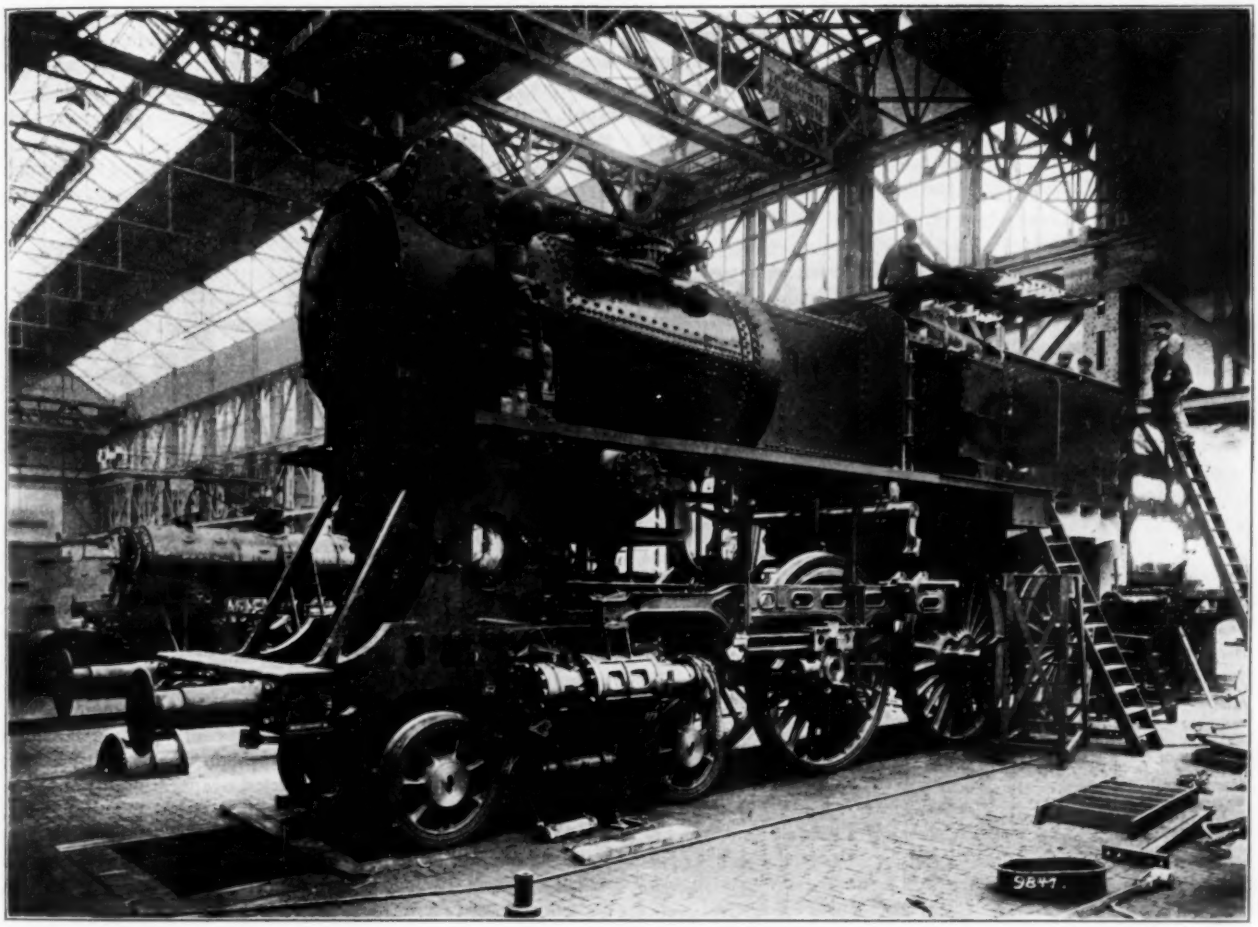
Journal bearings of motor trucks give but little trouble. Both A.R.A. and A.E.R.A. types are used.

Wheels

In some districts where many sharp curves are traversed, the flanges of the leading wheels wear rapidly.

Flange oilers reduce this wear, and wheel-truing brake shoes reduce the frequency of shopping for wheel turning. These shoes have carborundum inserts, and an occasional application keeps the wheels close to correct contour. Rolled steel wheels are used.

It is desired that a recital of these troubles does not leave the impression that rail-car operation is attended with unusual difficulties, for, to the contrary, the Union Pacific has found them to be an economical and attractive means of transportation.



THE SCHWARTZKOPFF-LOEFFLER LOCOMOTIVE IN PROCESS OF CONSTRUCTION

High-Pressure Locomotive Developments

BY A. E. STUEBING,[1] NEW YORK, N. Y.

This paper discusses two types of high-pressure locomotives recently built, the Loeffler type and the Winterthur locomotive. The former is an express locomotive of about 2500 hp. with a pressure of 1470 lb. per sq. in. and the latter of about 1200 hp. with a boiler pressure of 850 lb. per sq. in. The Loeffler locomotive is expected to result in a fuel saving of from 40 to 45 per cent compared with modern superheated locomotives. In a road test of the Winterthur locomotive, but 330 lb. of coal was necessary for firing up as compared with double the amount necessary for a conventional locomotive of equivalent output.

PROBABLY the most important development in high-pressure locomotives during the past year has been the more extensive application of the Schmidt double-pressure type. A locomotive of this type has been built in England for the London Midland and Scottish Railroad, and another in France for the Paris–Lyons Mediterranean System. Designs are being prepared for a 4–8–4 type to be tried on the New York Central and a 2–10–4 type for the Canadian Pacific.

The Delaware and Hudson Railroad, as the result of several years' experience with the locomotives Horatio Allen and John B. Jervis, operating at pressures of 350 lb. and 400 lb. per sq. in., has decided to go still farther, and has ordered a locomotive to operate at 500 lb. pressure. The design of the boiler is similar to that of the two earlier locomotives worked out by John E. Muhlfeld, and the engine will adhere to the cross-compound cylinder arrangement.

Many new arrangements are being proposed, some apparently having meritorious features, and others seemingly quite impractical. So much space would be required to describe all that have been proposed that it seems advisable to limit this paper to a discussion of two locomotives recently built, namely, the Loeffler type built by the Berliner Maschinenbau Actien Gesellschaft, sometimes referred to as the Schwartzkopff-Loeffler locomotive, and the locomotive constructed by the Swiss Locomotive and Machine Works of Winterthur.

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[1] Chief Engineer, Bradford Corp. Mem. A.S.M.E.

Contributed by the Railroad Division and presented at the Annual Meeting, New York, N. Y., Dec. 2 to 6, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

The Loeffler High-Pressure Locomotive

The Berliner Maschinenbau Actien Gesellschaft has been licensed to build locomotives according to the new and unusual design using high pressure patented by Professor Loeffler, and has received from the German State Railways an order to design and build an express locomotive of about 2500 hp. with a pressure of 1470 lb. per sq. in. In close cooperation with the German State Railways, the design of the locomotive shown in the illustrations was worked out. The manufacture of this locomotive is in progress, and it is expected that it will be ready for test soon.

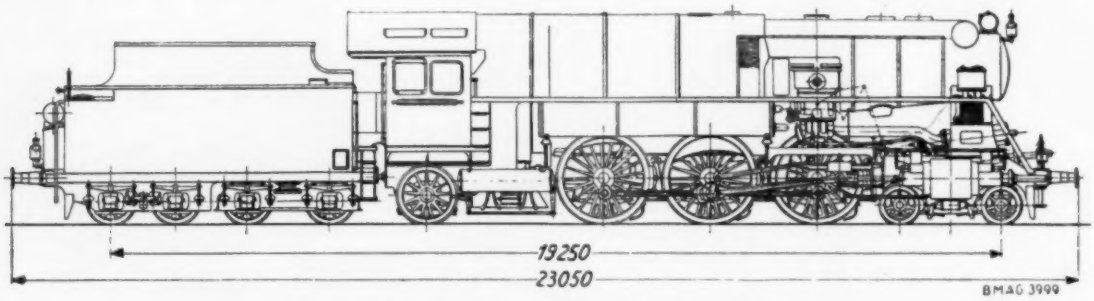


Fig. 1 Side Elevation of Loeffler Locomotive
(The total wheel base is 63 ft. 2 in. and the overall length 75 ft. 7 1/2 in.)

TABLE 1 PRINCIPAL DATA ON THE SCHWARTZKOPFF-LOEFFLER LOCOMOTIVE

Weight in working order, without tender	253,000 lb.
Adhesive weight	132,000 lb.
Diameter of drivers	79 in.
Diameter of leading wheels	33 1/2 in.
Diameter of trailing wheels	49 in.
Steam pressure in high-pressure system	1700 lb. per sq. in.
Steam pressure in low-pressure system	200 lb. per sq. in.
Diameter of high-pressure cylinders	8 5/8 in.
Diameter of low-pressure cylinder	23 5/8 in.
Stroke	26 in.
Maximum speed	75 m.p.h.
Weight of tender in working order	165,000 lb.
Water capacity	8500 gal.
Coal capacity	11 tons
Length of locomotive and tender	75 ft. 7 1/2 in.

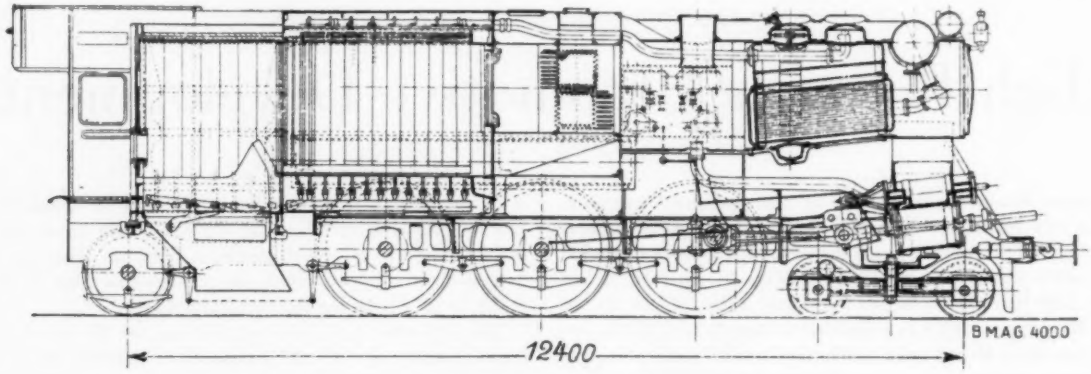


Fig. 2 Section of the Loeffler High-Pressure Locomotive
(The total wheel base is 40 ft. 8 1/4 in.)

According to the Loeffler system the steam is generated in an evaporating drum which is not exposed to the heating gases. Highly superheated steam of the same pressure, i.e., 1470 to 1760 lb. per sq. in., is introduced in a finely divided form into the water in the drum. The steam is taken in a saturated condition out of the steam space of the evaporating drum by means of a circulating pump, and is carried back into the water space of the same drum through a directly heated superheater. A portion of the highly superheated steam is taken off at a point beyond the superheater to do the work in the two high-pressure cylinders of the locomotive. This working steam is only a fractional part of the total steam which is handled by the pump, the steam to be circulated amounting to about 3.5 times the working steam. On account of the small specific volume of steam at this high pressure, the work of pumping the volume of steam necessary is relatively small, and amounts to only about 1 or 2 per cent of the work that can be obtained from the steam generated.

The walls of the firebox are made up of a portion of the tubular elements used for superheating the high-pressure steam, while the remainder of the superheater for the high-pressure steam is located at the front of the firebox. In this closed-tube system there exists a closed pure-water circulation, since the steam in the high-pressure cylinders which is reduced to about 256 lb. per sq. in. is carried into a heat exchanger after having its oil removed, and is there condensed, the condensate being led through a high-pressure preheater connected to the high-pressure superheater, and then back to the indirectly heated evaporating drum. The heat exchanger is used for the generation of low-pressure steam, and furnishes steam at about 214 lb. per sq. in. pressure.

The characteristic subdivision into a closed pure-water circuit with forced circulation, and the special low-pressure boiler was chosen in order to avoid impeding the heat exchange of the high-pressure portion even under the most unfavorable water conditions. High-pressure steam-generating systems, as a rule, are forced to use distilled water. In the Loeffler systems a normally pure feedwater will answer, since a concentration of the scale-forming material, and a deposition of scale is possible only in the unheated evaporating drum where the formation of scale can have no deleterious effect. The water is pumped at high velocity through the high-pressure preheater without any evaporation occurring. Therefore, it has been possible to make the subdivision into separate high-pressure and low-pressure circulating systems without any material loss in efficiency.

The low-pressure steam at about 214 lb. per sq. in., containing approximately 40 per cent of the total work energy, is superheated in a superheater which is also adjacent to the high-pressure superheater. It is allowed to expand in a center cylinder to about atmospheric pressure, and is then used to create draft by means of an exhaust nozzle. The ordinary draft arrangement is thus retained in spite of the closed high-pressure boiler circuit. The lower pressure boiler can be omitted in the Loeffler system because the circulation pumps have a certain reserve by which the boiler performance can be regulated within wide limits.

On account of the shortness of the boiler passages, the heating gases leave the high-pressure boiler while their temperature is still rather high, and therefore, the addition of a preheater for the combustion air seemed advisable. This air preheater is arranged between the smokebox and the superheater for the low-pressure stage.

The heat exchanger, which is not heated by the combustion gases, is arranged in front of the smoke chamber. In front of it in turn is the oil separator for the steam coming from the high-pressure cylinder, and also a preheater for the low-pressure water, from which the low-pressure feedwater passes to the plates in the clarifying dome, where scale-forming material is deposited.

The smokebox and heat exchanger are cylindrical members, and are secured in one piece with the high-pressure boiler so that the continuous form of the modern locomotive boiler necessary for bracing the frames vertically is obtained.

The arrangement of boiler, machinery, and accessories is shown in Fig. 2. The method of operation is as follows: A cylindrical drum partly filled with water constitutes the high-pressure steam generator. In firing up the locomotive, steam generated in some other boiler is used and carried to the pipe which opens into the lower portion of the drum, and is continued inside the drum by another pipe, the latter being perforated, thus giving free exit to the steam into the water, and causing an intimate mixing.

Steam gives up its heat to the water and generates thoroughly saturated steam in the drum, which leaves the steam space of the drum, and is taken off by two pumps which force this steam to the firebox. The firebox is composed of several gratings of steel tubes, and is extended forward by a tube system. The saturated steam reaching the firebox is forced through the tube members. The floor of the firebox is formed by a grate, below which is the ash-pan. Firing may be either by coal, oil, or pulverized coal.

The heat generated by the fire is given up to the steam flowing through the closed circuit of the tubes so that this steam becomes superheated. The steam thus superheated is forced by the rotary pumps to the check valve, and a smaller portion of it through the high-pressure regulator to the two high-pressure cylinders lying outside of the frames. The greater part of the superheated steam, however, is led through a return valve back to the drum. Here it gives up to the water the heat absorbed by it in the firebox and superheater, and again generates saturated steam, the same performance being repeated with continuous pressure and temperature increase.

As soon as steam of the pressure required for operation of the rotary pumps has been generated, the supply of external steam is shut off and the fire on the grates is started. The pressure in this circulating system is kept up to 1470 to 1760 lb. per sq. in., so that the same initial pressure is present in the high-pressure cylinders. The steam temperature after leaving the high-pressure superheaters is about 860 deg. fahr.

After the steam has performed its work in the high-pressure cylinders it leaves these cylinders at a pressure of about 265 lb. per sq. in., and flows through the check valve to the oil separator, whence it flows through the preheater for the low-pressure feedwater to the heat exchanger. This consists of a tubular drum with a steam dome and a feed dome, and a bundle of light gage pipes, which are rolled into the tube sheets. This tube bundle is closed off at the front by a cover which has a connection for the pipe leading from the low-pressure feedwater heater, and at the rear by a cover which has a connection for the condensate.

The exhaust steam from the high-pressure cylinders flows through tubes giving up its heat to the boiler water surrounding it in the heat exchanger, and this generates saturated steam in the boiler. At the same time the high-pressure exhaust steam is condensed, the condensate flowing to the condensate drum.

The low-pressure steam of about 214 lb. per sq. in. generated in the heat exchanger, flows into the low-pressure superheater which is also surrounded by heating gases and is there superheated to about 660 deg. fahr. It then flows through the pressure regulator to the low-pressure cylinder which is arranged inside the frame. After having done its work in this cylinder, the steam flows through the exhaust nozzle into the smokebox and to the stack.

The distribution of the work in the three cylinders of the locomotive is so chosen that the two outside cylinders each do about 30 per cent, and the inner cylinder about 40 per cent of the total for the locomotive.

The two rotary pumps whose first function is to pump the saturated steam out of the drum through the firebox and the high-pressure superheater, are three-crank steam pumps, and their dimensions are such that each of them can do 75 per cent of the maximum work. There is, therefore, a reserve of 100 per cent for average performance. The pumps are operated by steam generated in the heat exchanger and superheated in the low-pressure superheater.

The fire can be started in the firebox only when the pipe system is already filled with steam that is being pumped through them, and in order to shorten the time required to fire up, provision is made to operate the circulating pumps with steam generated at an external point. If there is no external steam supply available, a small auxiliary heating plant for the heat exchanger may be provided by means of which steam may be generated first in this drum to operate the circulating pumps, and to take care of the steam generation in the high-pressure drum.

With the circulating pump there is connected a feedwater pump for the high-pressure drum. This pump sucks the condensate of the exhaust steam out of a container into the pump cylinder, and forces it into the preheater for the high-pressure feedwater which also lies in the current of heating gases. From here it is forced to the high-pressure drum.

Inasmuch as the pumps for the high-pressure feedwater and the circulating pumps run at the same rate, an independent means of regulating the amount of feedwater is provided by a bypass. It may be necessary while the circulating pumps are operating temporarily, to prevent carrying feedwater into the high-pressure drum and a bypass is, therefore, provided for the condensate by means of a valve, so that the condensate which has been sucked in may be pumped back into the heat exchanger during which process it again gives up the heat absorbed in the preheater to generate steam in the heat exchanger.

On account of leaks in stuffing boxes, pipe connections, etc., there will be some loss of steam in the closed circuit of the high-pressure portion, and these leaks are made up by boiler water from the heat exchanger. This make-up water is carried by means of a pump (which is also connected to the circulating pumps) to the condensate drum, and from there to the high-pressure drum. This make-up water supply is automatically regulated when the water is in the high-pressure drum by means of a float in the condensate drum.

To feed the heat exchanger there is provided an injector which forces water from the tender into a feed drum which is equipped

with a purifier, and as a second means of feeding there is provided a feedwater pump which forces water from the tender to the preheater which is heated by the high-pressure exhaust, and then it goes into the feedwater drum. A pipe is provided for carrying high-pressure steam into the heat exchanger, if there should be temporarily too small a steam generation in the heat exchanger.

For safety devices the ordinary safety valves are provided for both the high-pressure and low-pressure systems, and further if in the most extreme case both circulating pumps should fail the fire on the grate can be put out. For this purpose a blow-off valve is placed in a pipe which is operated when the temperature gets too high, and from which a steam line is carried to the firebox.

In order to obtain the greatest possible thermodynamic economy a preheater for the combustion air is located in the current of hot gases. This preheater is arranged on both sides of the locomotive, and the air is carried through a pipe system which is heated by the gases with counter flow. From it, the air which has been heated to 300 deg. fahr. is carried to the ashpan under the grate by two channels arranged under the running boards.

The sub-division of the high-pressure and low-pressure circuits of the feedwater furnishes an effective possibility for a wide margin of power to care for overloads both on account of the water contained in the high-pressure evaporator, and on account of the relatively large water content of the heat exchanger.

The safety of the new locomotive can confidently be said to be at least as great, if not greater, than that of the present locomotives since the evaporation occurs only in evaporators which are not exposed to hot gases, whose walls are heated on both sides, and which are formed without pipe connections.

The operation of the superheater by means of the forced circulation of the high-pressure steam with its high heat absorption is essentially safer than that of the present superheaters in low-pressure locomotives. Corrosion and burning of the superheater pipes are thoroughly prevented, the temperature of the wall being only 70 to 85 deg. fahr. higher than the temperature of the steam.

In the new locomotive the parts of the locomotive boiler of the usual type which require special repairs have been avoided. These include staybolts, expanded tubes which are exposed directly to the fire, riveted joints, etc. The separate steam circuit and the fact that the operating steam is taken out of the superheater circuit prevents water from being carried over, and always gives dry steam for the engine so that damage to the cylinders by water is prevented.

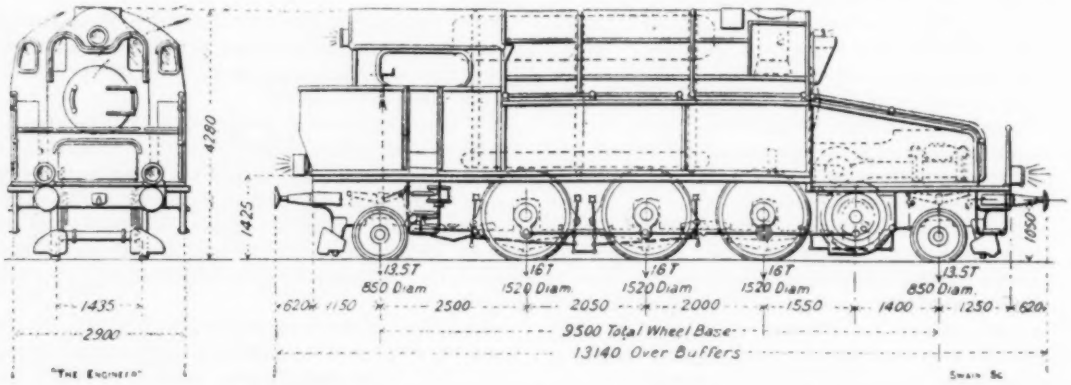


FIG. 3 GENERAL ARRANGEMENT OF WINTERTHUR HIGH-PRESSURE LOCOMOTIVE
(The total wheel base is 31 ft. 2 in., the length over buffers 43 ft. 1¼ in., the height 14 ft. ½ in., and the width 9 ft. 6¼ in.)

ADVANTAGES OF THE LOEFFLER HIGH-PRESSURE LOCOMOTIVE

Theoretically, the locomotive described should furnish a fuel economy of 47 per cent compared with modern superheated locomotives, and actual savings of 40 per cent to 45 per cent can therefore be confidently expected, which means an improvement in the total thermal economy of 80 per cent to 90 per cent.

With regard to the demand for greatest reliability and simplest maintenance which is desired in combination with the increase in economy of the locomotive, the following claims are made: The firing of the locomotive is made very much easier on account of the materially smaller grate for equal power. The materially smaller coal consumption makes it possible to increase the capacity of the locomotive. The water demand is also approximately only one-half that of the present locomotives so that with a tender of about the same size, the locomotive may run twice as long without taking water. The method of regulating the work according to the speed remains as in the present locomotives, namely by means of the valve gear.

By subdividing the boiler into a pure-water high-pressure portion, and a raw-water low-pressure portion, great safety is obtained for the high-pressure portion. The preheater for the high-pressure portion, which also is under high pressure, remains entirely clean even during long periods of service. Scale formation in the high-pressure portion of the locomotive, together with its injurious consequences, is entirely eliminated. On the other hand, a very complete absorption of the heat from the combustion gases is assured through the use of the high-pressure preheater.

In normal operation the steam is carried to the engine at a pressure of about 1470 lb. per sq. in. When the locomotive is standing still the pressure in the boiler can be raised to about 1760 lb. per sq. in. before the safety valves blow off. Due to this and to the small radiation to the superheater pipes, practically all the stand-by steam losses of the locomotive through steam blowing off, are avoided. A high-pressure locomotive of this type can be designed so that it will give the same output as the present low-pressure locomotives with about the same weights and the same dimensions. The coal and water saving can, therefore, be fully realized.

THE WINTERTHUR HIGH-PRESSURE LOCOMOTIVE

Early in 1926 the Swiss Locomotive and Machine Works decided to build a high-pressure locomotive which would work at a maximum boiler pressure of 850 lb. per sq. in., with an average working pressure of about 700 lb., thereby giving a certain working range between the average boiler pressure and the blowing-off pressure. Such a range allowed for a short period of overload, and compensated for the limited water capacity of the boiler, which in the final design was only about half that of the conventional locomotive boiler. From the first, condensing was ruled out on account of the complications it would necessarily have

introduced. Again, a high-speed uniflow engine with reduction gear was decided upon. With a geared locomotive it was possible to construct a standard engine, and to use different gears to meet the varied requirements of express, passenger, or freight service. Again, with a geared locomotive the irregularity of drive, which in the ordinary steam locomotive may be on occasion as high as 25 per cent at the driving wheels is reduced by gearing to 8 or 10 per cent. By this means it is claimed that the adhesive weight of the locomotive is utilized more effectively, so that either the tractive effort may be increased for equal axle pressure, or the number of driving wheels reduced with a corresponding decrease both in weight and first cost. It may also be pointed out that with a spring-borne engine the hammer blows due to the counterbalance are largely eliminated.

For reasons both of simplicity and reliability, a single-expansion engine working on the uniflow principle with poppet admission valves was decided upon. The boiler and engine were constructed first, and these were tested thoroughly for a year on the stationary test bed at the Swiss Locomotive Works. The results obtained were so favorable that the locomotive itself was then built.

The illustrations show the locomotive in its finished form. Details of the design are given in Table 2.

TABLE 2 WINTERTHUR LOCOMOTIVE DATA

Length over buffers	43 ft. 1 5/16 in.
Total wheel base	31 ft. 2 in.
Overall height	14 ft. 1/2 in.
Overall width	9 ft. 6 3/16 in.
Boiler Details	
Boiler pressure	850 lb. per sq. in.
Heating surface of water tubes (fire side)	1050 sq. ft.
Diameter of water tubes	2 3/8 in. inside
Diameter of water tubes	2 3/4 in. outside
Length of top high-pressure drum	14 ft. 9 in.
Internal diameter of top high-pressure drum	2 ft. 2 in.
Length of bottom high-pressure drums	14 ft. 8 in.
Internal diameter of bottom high-pressure drums	7 7/8 in.
Water content at mean level	95 cu. ft.
Area of water surface	31.5 sq. ft.
Heating surface of superheater	215 sq. ft.
Diameter of superheater tubes	2 in. inside
Diameter of superheater tubes	2 3/8 in. outside
Number of high-pressure superheater elements	7
Grate—	
Length	5 ft. 4 1/2 in.
Width	2 ft. 7 1/2 in.
Area	14.4 sq. ft.
Steam Engine Particulars	
Diameter of driving wheels	56 in.
Number of cylinders, single-stage expansion	3
Diameter of cylinders	8 1/2 in.
Piston stroke	13 3/4 in.
Volume of cylinders	738 cu. in.
Clearance—	
Front	5 per cent
Back	5 per cent
Gear ratio	1:2.5
Maximum speed	50 m.p.h.
Weight empty	70.3 tons
Weight in working order	84.0 tons
Tank capacity	13.20 Imp. gal.
Coal capacity	3.0 tons

As will be seen from the illustrations, the water-tube boiler is placed directly on the frames, and it is fitted with a smokebox and exhaust nozzle with a very short stack at its forward end. The boiler is somewhat shorter than usual in relation to the wheel base, and it allows the geared steam engine to be placed in front. Another advantage of this arrangement is that the engine, with the covering hood withdrawn, is accessible from all sides. Power is transmitted through a jack shaft to the driving wheels by means of side rods. As the illustration shows, the cab, side water tanks, and coal bunkers are arranged in the usual way.

The front hood covering the engine protects it against dust and dirt, and reduces the loss of heat due to radiation. At the same time it allows convenient access to the smokebox and the front air-inlet flues. The working principle of the new locomotive is illustrated in Fig. 4, and details of the boiler construction are shown in Fig. 5. The combustion chamber of the boiler is closed in by the tube elements, and is fitted with a normal type of firegrate. The heated gases pass through the water wall past the short stay tubes and reach the superheater and the feedwater preheater, which are accommodated in the boiler flue in front of the firebox. There is an air preheater arranged in the smokebox, and the products of combustion, having given up most of their heat, are expelled by the action of the exhaust, which intensifies combustion in the ordinary manner. The air which is required for combustion is taken in through two openings arranged in the front wall of the smokebox, which are protected by two cowls. It passes through the preheater, and is carried by means of a duct to the underside of the grate. Steam is taken from the regulator on which two safety valves are fitted, and passes through the superheater to the engine. The exhaust steam is led directly to the nozzle, but there is a branch connection to an exhaust-steam preheater for the feedwater. A supply of auxiliary steam from the cab is taken for the feed pump, and this is superheated in a separate coil. The feed pump is of the high-pressure compound type, and its duty is to lift the water from the feed tank, and force it through the feedwater heaters. The first is heated by the exhaust steam from the feed pump, and by a part of the steam from the engine cylinders.

The feedwater is thus heated up to about 175 to 195 deg. fahr. before it enters the main feedwater heater within the boiler itself, in which it is raised to the boiling point before it passes through the check valve into the top boiler drum.

The arrangement of the various heating elements may be noted. The generating elements, the superheater, feedwater heater, and air heater are placed in series, so that the heat from the gases is fully utilized, and only small surfaces are required, while a high degree of efficiency is attained. An important feature of the system is that there is no incrustation or scaling in the steam-generating elements themselves, any action of this kind taking place in the exhaust steam and main feedwater heaters, which are designed so that they can be inspected and scaled conveniently.

Boiler Design and Construction

Fig. 5 shows the boiler construction. The large-diameter top drum acts as a steam accumulator, and it is connected with the two smaller bottom drums by means of tube elements. The drums are also interconnected by the water-space walls, which are made of flanging-quality steel connected by short stay tubes. The water-space walls are welded to the drums. When the boiler is assembled and welded it forms a very stiff structure, which it is claimed, is particularly well adapted for locomotive work. Before the actual boiler was built each part was tested separately, and a series of boiler and heater elements were subjected to very high water and steam pressures, with rapid changes of temperature, without showing any defects. Both the superheater and the feedwater preheaters are built in such a way that they can be dismantled easily into simple pipe units for thorough inspection.

The High-Pressure Steam Engine

The steam engine works on the double-acting uniflow principle. Its principal dimensions are given in Table 2. The separate cylinders are bolted to a flange on the crankcase, which is placed

between the frame plates, and acts as an effective cross stay. A three-cylinder arrangement was chosen as giving the minimum number of cylinders, and at the same time a relatively simple distribution gear without sacrificing uniformity in torque and ease of starting. The valves are of the single-seated poppet type, and are operated mechanically by stepped ahead and reverse cams arranged on a sliding camshaft. There are six cams for each direction of running, and the camshaft is driven from the crank shaft through spiral bevel gearing.

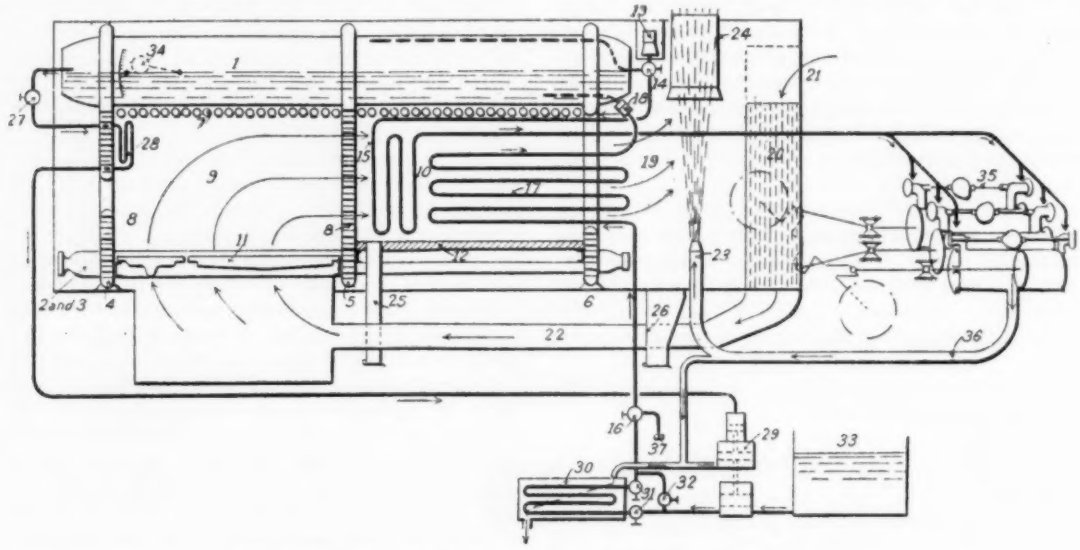


FIG. 4 DIAGRAM OF OPERATION OF THE WINTERTHUR LOCOMOTIVE

(1, top boiler drum; 2 and 3, bottom boiler drums; 4, back wall of firebox; 5, front wall of firebox; 6, front wall of boiler; 7, tube elements; 8, stay-tubes; 9 firebox; 10, superheater and preheater chamber; 11, firegrate; 12, refractory floor; 13, safety valve; 14, throttle; 15, superheater; 16, check valve; 17, feedwater preheater; 18, check valve; 19, smokebox; 20, air preheater; 21, intake openings of air preheater; 22, air duct; 23, blast pipe; 24, stack; 25 and 26, cleaning shafts; 27, stop valve for auxiliary steam supply; 28, superheater for feed pump; 29, feed pump; 30, exhaust steam preheater; 31, stop valve [normally open]; 32, stop valve [normally closed]; 33, water tank; 34, water-level float; 35, steam engine; 36, exhaust pipe; 37, filling connection.)

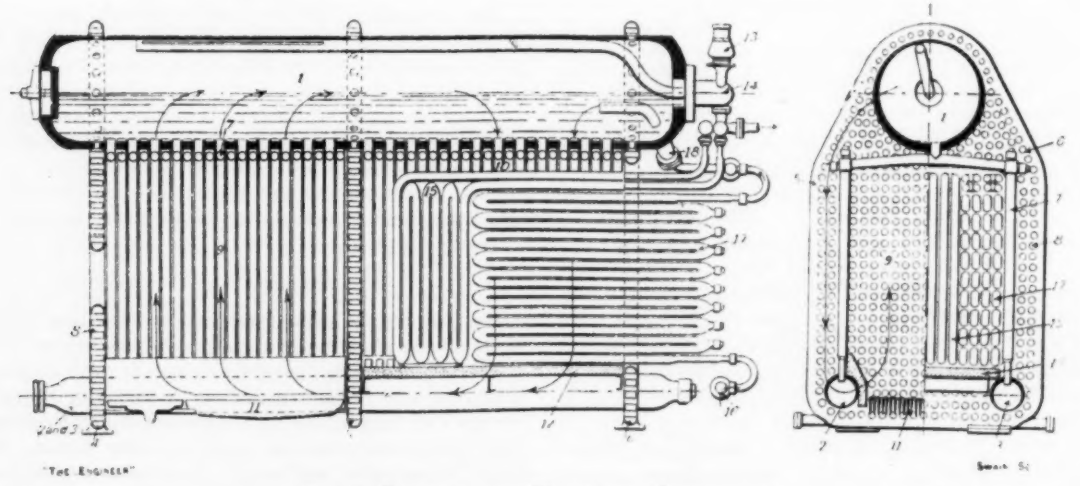


FIG. 5 BOILER OF THE WINTERTHUR LOCOMOTIVE

(1, top boiler drum; 2 and 3, bottom boiler drums; 4, firebox back wall; 5, firebox front wall; 6, front wall of boiler; 7, tube elements; 8, staytubes; 9, firebox; 10, superheater and preheater chamber; 11, firegrate; 12, refractory floor; 13, safety valve; 14, throttle; 15, superheater; 16, clack-box; 17, feedwater preheater; 18, check valve.)

STATIONARY AND ROAD TRIALS

Extensive bench trials were run with the engine arranged on a special stationary test bed, and the boiler and engine were tested thoroughly over a total running period of 350 hr. At first the superheat was a little high, but that was remedied by reducing the surface of the superheater. In the early trials it was also necessary to make some alteration in order to regulate the combustion, but when they had been made, the boiler was shown to be satisfactory in every respect. Under normal load conditions a total of 8500 lb. of steam per hour, not including the steam required for the feed pump, were produced, which corresponds to an evaporative factor of 8, and a production of nearly 600 lb. of steam per square foot of grate surface per hour.

Some of the actual pressure and temperature readings are as follows: With an initial feed temperature of 70 deg. fahr., the water was raised to 190 deg. fahr. in the exhaust-steam preheater, and further to 450 deg. fahr. in the main preheater within the boiler. The feedwater thus entered the top drum at a temperature of 50 to 70 deg. fahr. below the boiling point. The feed heating was, therefore, practically complete, while the range of super-

heat from 720 to 780 deg. fahr., according to the load, was higher than that used in conventional locomotives.

In the bench trial the steam engine was tested under load, being run for 8 1/2 hr. several times in order that reliable consumption figures could be obtained. The indicator diagrams were not unlike those of a Diesel engine with a high compression and a strongly marked admission. The stepped cam operating the inlet valve gear can be set on one of six positions. Positions 1 to 5 are those for running, and position 6 is for starting only. With a boiler pressure of between 700 lb. and 780 lb. per sq. in., and with the engine running at a speed of 550 r.p.m., the following outputs were recorded by the brake: Position 1, 470 b.hp.; 2, 800 b.hp.; 3, 1000 b.hp.; 4, 1200 b.hp., which is a very good performance for an engine weighing, with all its accessories, only 10,800 lb. The average steam consumption was 13.2 lb. per b.hp-hr. corresponding to 1.75 lb. of coal per b.hp-hr. After the tests had been made the whole plant was examined carefully, and no solid scale was found in the boiler. A fine mud had collected in the lower high-pressure drums, which was easily washed off.

The first road tests were carried out in November, 1927, and the engine was shown to be very smooth on the road and easily started. Only 330 lb. of coal were necessary for firing up compared with double the amount necessary for a conventional locomotive of equivalent output. The boiler was steamed within 1 1/4 hours of lighting up. Comparative road tests were made in January with a conventional 170 lb. pressure twin-cylinder superheated locomotive of the B 3/4 type No. 1341, belonging to the Swiss Federal Railways, of equal output, and under similar conditions as regards train load, express trains of 250 tons to 300 tons being hauled. This locomotive had a grate area of 23.7 sq. ft., compared with the 14.3 sq. ft. grate of the high-pressure locomotive. The accompanying table shows the results of the tests.

COMPARATIVE TEST RECORDS OF LOW- AND HIGH-PRESSURE LOCOMOTIVES

Section	Load in tons, excluding locomotive	Type of train	Locomotive boiler pressure, lb. per sq. in.	Coal consumption Lb. total	Coal consumption Lb. per b.hp-hr.	Water consumption Lb. total	Water consumption Lb. per b.hp-hr.	Percentage savings, high pressure against low pressure Coal Per cent	Percentage savings, high pressure against low pressure Water Per cent
Winterthur-Romanshorn-Winterthur	350	Express	170	2760	4.1	23,600	35.0	35.5	51.0
			850	1890	2.65	12,300	17.2		
Winterthur-Romanshorn-Winterthur	350	Passenger	170	3740	3.64	31,700	30.8	30.5	36.0
			850	2660	2.50	20,500	19.7		
Winterthur-Stein Sachkingen-Winterthur	445	Direct goods	170	3410	4.08	30,600	36.7	25.5	38.3
			850	2460	3.04	18,500	22.6		
Winterthur-St. Gallen-Winterthur	300	Express	170	2590	4.08	23,100	36.3	38.4	42.5
			850	1730	2.51	14,500	20.9		

A locomotive of the same type has been designed for an output of 3000 hp. with a 4–8–2 wheel arrangement and separate tender. The weight of the locomotive is estimated at 145 tons and of the tender 70 tons. The overall length is 77 ft., the height 14 ft. 1/2 in., and the width 10 ft. 1/2 in.

The writer desires to acknowledge his indebtedness to the manufacturers for information, and to the paper by Herbert Brown before the Institution of Locomotive Engineers for details of the Winterthur locomotive.

Discussion

JOHN E. MUHLFELD.[2] The paper gives the most detailed descriptive information relating to Loeffler and Winterthur (Wiesinger) types of high-pressure locomotives that has come to the writer's attention. It is interesting to note that the Loeffler locomotive of about 2500-hp. capacity, making use of a maximum of 1470 lb. steam pressure, with a total temperature of 860 deg. fahr., will produce a fuel saving of from 40 to 45 per cent; and that the Winterthur locomotive, of about 1200-hp. capacity, with a total temperature of 720 to 780 deg. fahr., will produce a fuel saving of from 25 to 35 per cent. These performances indicate that relatively high steam pressures and temperatures can be made use of in steam locomotives, not only safely but with substantial results in efficiency and economy.

There is an economic urge for further improvement if the steam locomotive, which can be designed to operate at a much greater overall efficiency and economy than any other mobile unit of equivalent hauling capacity, is to forge ahead as a transportation machine. According to Geo. A. Orrok, in 1919 the steam central power stations in the United States produced a total of about 32 billion hp-hr. at an average of 2.34 lb. of coal per hp-hr. By 1928 central-power-plant economy had been so much improved that the average cost for the 71 billion hp-hr. that year was only 1.34 lb. of coal per hp-hr. More than 20 of the larger stations now use less than 1.12 lb., and six are averaging at or about 0.8 lb. of good coal per hp-hr. These comparative figures are deserving of serious consideration by railway executives.

A greater investment per unit of drawbar pull can be justified in a steam locomotive operating in a relatively level country with a high average load factor than one operating in a rolling and mountainous country with a relatively low load factor. However, any engineering improvements that will produce greater boiler efficiency and capacity, and fuel savings equal to 10 per cent or more net, are worthy of practical application.

Of the questions of predominating interest to steam-locomotive users, the tendency toward higher steam pressure and higher combustion and superheated-steam temperatures, which decrease the heat units required and improve the efficiency of the transformation of calorific energy into mechanical work, is the most popular. From developments to date initial steam temperatures can be considerably increased without lubrication, maintenance, or dissociation or velocity of steam difficulties, so that the resuperheating of steam between high- and low-pressure multiple-expansion cylinders will not be required as steam at 500 lb. pressure, when superheated to a total temperature of 1000 deg. fahr. will be dry when it is expanded adiabatically to the atmosphere.

The problem, however, is what shall the limit of pressure and temperature be to take advantage of these favorable qualities? The writer believes that in a non-condensing steam locomotive, 500 lb. steam pressure and 850 deg. fahr. temperature is a reasonable limitation, at least with the present state of the metallurgical art and of the utilization of the pressure-heat combination. An

[2] Railway Consulting Engineer, New York, N. Y.

attempt to use, in a practical and economical manner, the theoretical advantages of a higher pressure-temperature in a multiple and regenerative type of locomotive will be a very difficult proposition.

The first waste of heat units occurs in the furnace, and the boiler, therefore, requires urgent attention, after which the steam distribution gear must be improved to provide quicker and larger admission and exhaust openings and greater precision, reduce the cylinder and piston clearance spaces, and improve the means for the utilization of the exhaust steam and the flue gases to heat the feedwater and the combustion air.

Much has been said about the dissociation of hydrogen and oxygen in high-pressure-temperature steam with resulting oxidation of the metal with which the steam is in contact. The dissociation of steam in contact with steel at high temperatures has been observed in the presence of hydrogen, in both saturated and superheated steam, and traces of it have been found in water as it enters and leaves the feedwater heaters. Therefore, unless combustion is completed before the furnace gases reach the superheater elements, and the steam velocity is high and the flow is properly distributed between the superheater elements, the low-carbon steel tubes may reach temperatures at which oxidation, due to steam dissociation, will occur. However, reports made to date by the research department of the Detroit Edison Company and the Prime Movers Committee of the American Society of Mechanical Engineers indicate that any dissociation which may ordinarily obtain is apparently so infinitesimal that it will have no serious effect on material now obtainable which can be used in the parts subjected to such steam.

In the boiler design serious consideration should be given to the use of all possible self-supporting shapes. A sphere requires the least material to contain a given volume and pressure, and the more spherical and cylindrical hollow shapes used in the design of a boiler, the greater will be its volumetric and self-supporting capacity per unit of tare weight. Other essentials in locomotive boiler design are: Maximum firebox volume and evaporation surface and gas area through fire flues and tubes; relatively short fire flues and tubes in combination with combustion chambers versus longer flues and tubes without combustion chambers; increased combustion temperature by limiting the size of the grate area or by burning fuel in suspension; full utilization of radiant heat for evaporation; rapid circulation of water through or around all evaporation surface plates, siphons, and tubes; removal of all steam-delivery pipes and throttle valves from inside the boiler and smokebox; an adequate water capacity and saturated-steam space at the top of the boiler and the collection of the saturated steam from over a large surface area of the steam-generating water, to avoid priming and the use of the superheater as a secondary evaporator. The steam-delivery pipe and main throttle valve should be of such design and dimensions as will reduce the frictional resistance between the boiler and the steam chests to the minimum.

With respect to the superheater equipment, in order to increase the firetube gas area, reduce the cylinder back pressure, and increase the engine tractive power, it would be preferable to remove the superheater elements from the fire flues, either completely or in part, in order to provide for the free passage of the products of combustion and reduce the liability for their obstruction. As the net gas area and length of the fire flues and tubes govern the amount of draft required to burn a certain amount of fuel, the smaller this net area the more draft will be required, and the greater will be the engine horsepower loss resulting from the increased cylinder back pressure. Such an arrangement of a counterflow type of superheater would also prevent the present loss of heat due to the superheated steam being required to traverse the coldest part of the boiler, and would enable reduction of existing wasteful smokebox temperatures without loss of superheat, and carrying on the superheating process in a zone of higher gas temperature would reduce the pressure drop, or loss of steam pressure, between the boiler and the cylinders. Even with the conventional fire-flue type of double-loop superheater elements, a reduction in the forward-end length of the upper-loop portion, in order to eliminate more of the superheater heating surface from the cold zone of the boiler, i.e., locate the upper forward return bends about one-third of the flue length from the front-tube sheet, should be advantageous.

The average coals in the United States, when burned in locomotives on grates and fired either by hand or mechanical stoking, will produce the best results when the grate area is proportioned for the burning of from 90 to 110 lb. of coal per sq. ft. of grate area. However, the usual method of firing and burning run-of-mine or sized grades of coal and other solid fuels on grates is a clumsy, inefficient, and uneconomical method for obtaining its heat value. By pulverization and burning coal in suspension in the same manner as gas or oil, the fuel and air can be regulated to produce almost perfect combustion under all conditions of working; maximum radiant-heat absorption will be obtained; smoke and standby losses are reduced to the minimum; the discharge of unconsumed fuel is largely reduced; and a great heat value of the fuel is obtained.

In the utilization of the waste heat in the exhaust steam and flue gases for feed-heating with the higher boiler pressures, i.e., from 250 to 500 lb. pressure, an exhaust-steam injector in its present state of practical development seems to be out of the question, and a mechanically driven feed pump will substantially reduce the life steam required for the boiler feed operation, for the reason that the higher the boiler pressure the greater will be the live steam consumption for this purpose with a direct steam-driven feed pump. Also the most effective feedwater heater is the one which allows the best use of the heat in the exhaust steam, with the smallest use of live steam. Therefore, the open type of condenser or heater appeals, because it uses the total heat of the exhaust steam, and in addition about 13 per cent less water need be heated, due to the reclamation of the condensed steam.

Scientific treatment of unsuitable boiler water is most essential to prevent priming, foaming, and the depositing of scale, with its resultant embrittlement and corrosive pitting and grooving action on the boiler metal. Likewise, pure water will dissolve iron, and when dissolved oxygen is absent a galvanic corrosion occurs.

In regard to the preheating of the combustion air, wherever the firing equipment is such that the fire doors can be kept closed, as in the case of oil and pulverized-fuel burning locomotives, then the preheating of the combustion air has many advantages. Where the furnace doors are opened, or can be left open, the use of preheated air cannot be of much practical benefit.

Cylinder back pressures, with exhaust-steam draft, should not exceed from 5 to 7 lb., and any improvement that will provide for greater entrainment of the smokebox gases by the exhaust steam or, if necessary, by mechanical draft, in order to lower cylinder back pressure, will be a marked step in advance. In some of the smaller and now obsolete types of steam locomotives with plain round long smokestacks and short exhaust-nozzles openings, the efficiency of the exhaust steam in creating smokebox vacuum and draft is, in some cases, as high as 30 per cent, whereas in the larger and more modern types of locomotives with the increased diameter and shorter smokestacks and higher exhaust nozzles, it is difficult to obtain an efficiency of 20 per cent, and the majority of these locomotives have stack and exhaust-nozzle equipment which will produce not more than from 5 to 10 per cent efficiency of the exhaust steam.

The location of all cylinders, valve chests, and valve gears outside of the main engine frames provides the most practical and accessible arrangement. This has been demonstrated for many years through the substitution of the Walschaerts type of outside for the Stephenson type of inside valve gear, and by the two-cylinder, single-expansion or compound, rigid-frame, and the four-cylinder single-expansion or compound, articulated-frame types of locomotives. Where rigid-frame locomotives are desired, and sufficient horsepower cannot be produced in two outside front cylinders, then consideration should be given to the application of two outside cylinders at each of the front and rear ends of the chassis, in combination with outside crankpins spaced at right angles in the usual manner, in preference to the use of intermediate third and fourth cylinders in combination with inside cranks and the complicated and inaccessible inside valve gear and reciprocating and revolving parts.

With high-pressure-temperature locomotives it is most important that the insulation, lagging, and jacketing of all of the boiler and engine parts and the piping, which are subject to radiation loss, be insulated to an efficiency from 96 to 98, or even higher.

In the use of the high-pressure-temperature steam it is of the greatest importance that an adequate range of expansion be provided, either by the compounding or uniflow principle. Limiting the cut-off merely results in limiting the otherwise available boiler, engine, and adhesive weight capacity of the locomotive.

With a piston valve and outside-motion gear, decreasing the cut-off increases the compression, which gives high efficiency for normal working conditions only. With increased cut-off the compression becomes insufficient, and with decreased cut-off it will be too high, resulting in a part of the power being worthlessly used in the cylinder itself. Therefore, a rotative-motion outside-type of poppet-valve gear, wherein the cut-off can be independent of the compression, due to the separate admission and exhaust valves, which in themselves provide a certain uniflow and enable reduction in cylinder clearances, should be favorable to the more efficient utilization of the high-pressure steam in the engine cylinders. The cylinder indicated horsepower will also be increased by the quicker admission and exhaust opening and the smaller clearance spaces and reduced cylinder back pressure. This type of valve gear also has advantages in the utilization of a higher pressure-temperature of steam, with less lubrication and without the necessity for a power reverse gear. It also overcomes the disadvantages of the small areas for the entering and exhausting steam, even where the double-ported type of piston valve is made use of.

The principal advantages of uniflow are the flow of the admission steam from the hottest to the coldest point in the cylinder, and a reduction in the flow of heat from the cylinder walls to the steam, as well as a decrease in the cylinder port and piston clearance spaces. With uniflow the steam leaves the cylinder at its coolest point, and with the least opportunity to remove heat from the cylinder walls.

To reduce track-rail lateral and vertical pressures and stresses and rail wear, and to improve the guiding and riding qualities of the locomotive, lateral-motion devices that will equalize rail pressures between the leading truck and the forward driving wheels are not only essential but will, in many cases, enable the elimination of otherwise necessary non-productive truck wheels.

Nosing, fore-and-aft vibrations, and side swaying of a locomotive are due to track and rail conditions, the unbalanced reciprocating forces, and to wheel and rail clearances; deficiency in counterbalance results in hammer blows on the rail; and dynamic augment is due to excess balance on account of the reciprocating weights, and to the component of the piston thrust, which latter trackrail pressure may be somewhat reduced by the use of longer main rods.

Small diameter driving-wheel centers make the counterbalancing of a two-cylinder locomotive a difficult problem in other than the Mallet type of locomotive. In a three-cylinder type with the cranks spaced 120 deg. it is even more difficult because of the additional force at the main crankpins, due to the components of the piston thrusts resulting from the spacing of the cranks.

All revolving and reciprocating parts which must be counterbalanced should be designed of the minimum weight consistent with strength by the use of high-elastic-limit, tough, ductile material, and this applies as well to all other unsprung parts such as driving axles and wheel centers. The centers of gravity of the counterweights in each driving wheel should be designed as close as possible to the centers of gravity of the planes of the revolving and reciprocating parts.

The American Railway Association formula for counterbalancing, especially as applying to main driving wheels, is obsolete for modern locomotives which have the vertical planes of the revolving parts and the counterweights considerably removed. The counterbalancing of 100 per cent of the revolving weights, with the division of this counterweight pro rata between the main and the coupled driving wheels, and the counterbalancing of 50 per cent of the reciprocating weights, with an equal division of the same between the coupled, exclusive of the main driving wheels, should best take care of both the static and the dynamic loading.

In view of the axle-load limitations of existing track and bridge structures, new locomotive boiler, chassis and machinery, total and detail weights must be reduced to the minimum. This applies especially to the elimination of all unnecessary leading and trailing truck or non-productive wheels and to the unsprung weights in driving axles and wheel centers, main and side rods, and to the other revolving and reciprocating parts. As yet, alloys and heat-treated steels, when subjected to repeated loads and high pressures and temperatures, have not demonstrated the anticipated reliability, durability, and resistance to fatigue. The magnetic treatment of ferrous metals, now being experimented with, may be able to effect such changes in the sub-atomic structures as to produce more satisfactory results. In the meantime, service test of high-elastic-limit, low-carbon, high-manganese steel castings have shown remarkable resistance to stress and strain; to surface checking and progressive fracturing; and to corrosion, pittings, and grooving. It is predicted that with the rapid improvement being made in steel-casting production facilities, it may soon be possible to make use of high-pressure locomotive integral cast-steel boiler shells, wheel centers and axles, piston heads and rods, and main and side rods and like units as a substitute for rolled and forged parts, the metal of which now originates in a cast ingot. By this change, much of the present excess weight, forming, punching, shearing, riveting, welding, machining, fitting and fabrication, and the delay and cost incident thereto, can be dispensed with.

On the Delaware and Hudson, during the past five years, it has been found, in the "Horatio Allen" (D & H No. 1400) freight locomotive, making use of 350 lb. boiler pressure and multiple expansion; and during the past two and one-half years, on a similar type locomotive, the "John B. Jervis" (D & H 1401), carrying 400 lb. boiler pressure, that the use of these higher steam pressures, even in combination with relatively low superheat, without feed-heating and hand-fired, can develop high tractive power, comparatively large economies in fuel consumption, and can be handled with as great safety and with as little maintenance as the conventional superheated steam locomotive of 200 lb. pressure.

The Delaware and Hudson Company expects soon to have its "James Archbald" (D & H No. 1402), which will make use of 500 lb. pressure and from 700 to 750 deg. fahr. total temperature of the steam, in service as a final consummation of its experimental

work with locomotive high-steam pressure, at least for the present. This pressure will be utilized by multiple expansion, in the same manner as on the D & H Nos. 1400 and 1401. While the latter two locomotives have driving wheels of 57 in. diameter, those of the 1402 will be 63 in. diameter. Other changes and improvements will incorporate a Dabeg mechanically driven, double-acting type of feedwater pump-exhaust steam heater; Wagner single-seated type of balanced outside front end throttle valve; counterbalancing of the revolving and reciprocating parts of the locomotive for a speed of 75 m.p.h.; increased superheat capacity; greater boiler-flue and tube gas area; enlarged furnace volume; grate area limited to maintain maximum furnace temperatures; reduced cylinder-port and piston clearances; silico-manganese steel boiler plates; nickel-steel forgings and boiler tubes and flues; low-carbon, high-manganese steel castings; and insulation, lagging, and jacketing of from 96 to 98 per cent efficiency.

Comparing the "James Archbald" with the conventional steam locomotive carrying 200 lb. boiler pressure, making use of superheated steam in single-expansion cylinders, and equipped with exhaust-steam feedwater heating, it is calculated that it will perform equivalent work at the tender drawbar with approximately two-thirds less fuel. Inasmuch as next to labor the fuel bill is the largest single item of expense in steam-railroad operation, this reduction in fuel consumption will represent a very large saving in transportation expense.

The "Horatio Allen" and "John B. Jervis" locomotives are hand-fired, and with relatively low superheat and without feed-heating operate at 8.75 and 9.5 per cent, respectively, thermal efficiency, in terms of the heat value of the coal, at the tender drawbar. With the higher boiler pressure and superheat, feed heating, reduced cylinder and piston clearance space, increased diameter driving wheels, and other changes incorporated in the "James Archbald," it is calculated that it will operate at between 11 and 12 per cent thermal efficiency, in terms of the heat value of the coal, at the tender drawbar.

There seems to be but little question as to the ability to generate high-pressure and high-temperature steam, safely, successfully and economically, but the problem, as I see it, is how can this combination of pressure and heat energy be best and most efficiently converted into work in a locomotive engine and maintain a dependable and practical machine from the standpoint of fuel saving, operation, and maintenance? Experience on the Kansas City Southern Railway showed that steam at 250 lb. pressure, with a total temperature of 1000 deg. fahr., can be produced and used in a locomotive, but the cutting and disintegrating action of the steam on the various materials is a factor to be reckoned with. Experience on the "Horatio Allen" and "John B. Jervis" locomotives, during the past five years, has demonstrated that 350 and 400 lb. steam pressure, with moderate superheat, is satisfactory and economical, and that 500 lb. pressure in combination with about 850 deg. fahr. total temperature will be practical, but about as high in both pressure and temperature, as should be used with the present state of the metallurgical art and efficient utilization of the pressure and heat to convert it into work.

In the original design of the "Horatio Allen" high-pressure type of boiler, use was contemplated of it for both slow and fast freight, and also for high-speed passenger service. With the improvements that the railways are making on their main line roadways, in the way of easier curves, lower grades, deeper ballast, and heavier crossties, tie plates, rail, and other track appliances, there is no good reason why, in combination with grade separation, automatic signaling and automatic train control, steam locomotives and rolling stock cannot now be designed and operated at speeds of from 110 to 120 m.p.h. This rate of movement will afford much more intensive competition with airplane, airship, and various public highway means of passenger, mail, and express transportation, and with much greater safety, convenience, and comfort.

By applying the "Horatio Allen" high-pressure type of boiler, which is designed with a small-diameter main cylindrical shell in order to clear the driving wheels to a 4–6–2 or a 4–6–4 type of locomotive, with 500 lb. steam pressure, 850 deg. fahr. total temperature of the steam, 90-in. diameter driving wheels, and a modified system of uniflow steam distribution, the vertical center of gravity of the locomotive can be maintained sufficiently low for the higher speeds, and by eliminating stops, train schedules equivalent to commercial airplane service can be maintained readily. Existing steam locomotives, with smaller diameter driving wheels that have been operated at speeds of from 85 to 105 m.p.h., have demonstrated that the proposed higher speed is entirely safe and practicable.

With respect to the modern steam-locomotive design in general, it is suggested that the American builders and railway mechanical engineers give greater consideration to increasing boiler pressure, steam temperature, and sustained boiler-horsepower capacity; improving the utilization of the steam in the cylinders, and reclaiming the waste heat in the exhaust steam and smokebox gases.

H. B. Oatley.[3] In regard to steam temperatures obtained on American locomotives, one or more engines on the Delaware and Hudson Railroad are working with the steamchest temperatures above 800 deg. fahr. Engines on the Canadian National and the Canadian Pacific Railways are also working with temperatures in excess of 750 deg. fahr. Exhaust-steam temperature is higher with the longer cutoffs. The engines referred to are in freight service on the Western Maryland Railway and operate during a large proportion of their running time, with essentially full cutoff so that the mean steam temperature in the cylinder is higher than on high-speed locomotives working with the same initial steam temperature, but with relatively short cutoff. While the conditions on these Western Maryland engines are quite severe, there should be no serious trouble with lubrication nor with the packing on pistons and piston rods.

Stress has been laid on the large percentage savings of the Winterthur locomotive. While these figures are correct, as may be seen from the table given at the end of the paper, there is other significant data which should not be lost sight of. In the table referred to, the coal and water consumption per horsepower-hour is given both for the low-pressure and for the high-pressure locomotive. The coal consumption of the low-pressure engine ranges between 3.46 lb. and 4.10 lb. per hp-hr., and for the high-pressure locomotive the range was between 2.50 and 3.04 lb. per hp-hr. The low-pressure locomotive was far from economical in its performance, and while economies of from 25 per cent to 30 per cent are credited to the high-pressure locomotive, the unit consumption figures are by no means remarkable. Many engines of the conventional type, and with steam pressures not over 250 lb. per sq. in., have shown on the Pennsylvania Railroad testing plant and in dynamometer-car tests on the road both here and abroad coal-consumption figures lower than those shown by the Winterthur engine.

Data on the performance of high-pressure locomotives obtained on road tests are not available in such volume. Dr. Nordmann, however, has published in the March, 1928, issue of *Zeitschrift des Vereines deutscher Ingenieure*, some data obtained from road tests of the Schmidt high-pressure, double-pressure locomotive. It is shown that a coal consumption of 2.02 lb. per drawbar hp-hr. was obtained. This was with a fuel that had 12,700 B.t.u. per

[3] Vice-President in Charge of Engineering, The Superheater Company, New York, N. Y.

lb. The coal used on the Winterthur locomotive tests had 13,300 B.t.u. per lb. Compared therefore on a heat-unit basis, the consumption of the Schmidt engine was equivalent to 1.93 lb. per drawbar hp-hr. It may also be said that the tests of the Schmidt locomotive were conducted at speeds of 50 m.p.h., while the tests of the Winterthur engine were at average speeds of between 25 and 26 m.p.h. As the resistance increases with the speed, the performance of the Schmidt locomotive becomes very significant, and were the figures of both engines to be reduced to an indicated-horsepower-hour basis, the fuel economy of the Schmidt engine would be still more impressive.

A. Giesl-Gieslingen.[4] The Floridsdorf Locomotive Works in Vienna, Austria, developed the Loeffler system of steam generation. After the elements of construction had been exhaustively tested with perfect success, their 2000-kw. generating plant was adapted to use steam of 1700 lb. pressure and a temperature of 910 deg. at the boiler, 890 deg. at the engine. This temperature is maintained constant throughout the whole range of output, one of the special features connected with the Loeffler system. The newly installed reciprocating engine develops 500–600 hp. in a single cylinder of 6.7 by 18 in. at 300 r.p.m., exhausting into the earlier two-cylinder compound-condensing engine at about 200 lb. and 430 deg. A good grade of American cylinder oil and graphite is used. The total absence of lubrication troubles is due to the high pressures to which the oil is subjected at all times, as was clearly demonstrated by comparison with the Swiss locomotive. Tests carried out at Winterthur showed that the maximum steam temperature that could be safely carried was about 77 deg. as stated by Dr. Brown of the Swiss Locomotive Works before the Austrian Society of Engineers. That engine is of the single-expansion type, and there is approximately atmospheric pressure in the cylinder for about half the time, while, in the Floridsdorf compound the pressure never drops below 170 lb., which enables the carrying of higher superheat. This point seems not to have received consideration so far.

As to rod packings, a test plant was installed at Floridsdorf comprising a cylinder in which a piston rod was moved by electric drive with 20-in. stroke and 300 r.p.m. The packings were subjected to a constant steam pressure of 1500 lb. at 850 deg., representing more severe conditions than in normal service, where cylinder pressure is variable. Metallic and soft packings were received from many parts of the world and tests proved to be very time-absorbing. Holding tight was no problem, but damage to the rod often developed after more than 100 hr. of service. After having used pure soft asbestos with fairly good results, various metallic packings were found to be perfectly successful, while others failed entirely. The problem is solved, there being only a question of materials. A very hard surface of the piston rod is essential with these pressures.

An American Loeffler locomotive would probably look considerably simpler than it appears on the chart presented; the sharp guarantees that had to be given apparently influenced the designers.

An important fact should not be neglected when pointing out the most economical steam pressure or the increase in performance by the use of high-pressure steam: Contrary to the turbine, the reciprocating engine makes a much better use of the heat units available in the high-pressure part; the classic tests of Schmidt with his 850-lb. quadruple-expansion condensing engine of 1921 showed an efficiency of about 95 per cent compared with the Rankine cycle in the high-pressure cylinder, and a little over 70 per cent in the lower ranges. The conventional locomotive cylinder efficiency equals the latter figure, and there is a gain proportionally much more by the use of high-pressure steam than is shown by the Rankine cycle.

While Europeans look for fuel saving, Americans want increase in performance. In the design of heaviest power, these items proved to be closely related, as the limits of grate area and combustion space have been reached, and 5000 to 6000-hp. engines demand grates of over 100 sq. ft. in the conventional locomotive. The Loeffler engine, however, where the heat consumption should be nearly cut in half, has a grate area of 28 sq. ft. for a rated output of 2500 hp. This gives a good outlook for future development, as 10,000-hp. boilers will be possible within the existing clearance limitations, and 10,000 hp. is not at all out of question if one looks at the Virginian electrification and other developments of modern railroading.

Replying to Mr. Oatley's remark on the excessive fuel consumption of the normal locomotive which was compared with the Winterthur high-pressure design on the Swiss railways, this, indeed, is an important point, and the Swiss 2–6–0 type which has been taken for comparison is not up to date. It must be considered, however, that the high-pressure engine is the first of its kind and much can unquestionably be perfected to improve its efficiency. Great economic achievements have been made in conventional locomotive design during the last decade without fundamental changes in construction. The German standard Pacific of 1927 gets 25 per cent more work out of one pound of coal than the representative ten-wheeler of 1921, although the engines have both feedwater heaters and look of equal qualities to the average observer. Still, much remains to be done. Immediate development of the conventional locomotive is urged as great returns are possible by refinements in design and moderately higher pressures, until the field is ripe for general conquest by super-pressure steam.

James M. Taggart.[5] In connection with the development of high steam-pressure locomotives it seems proper to take into consideration the experience which has been obtained in the generation and utilization of high-pressure steam in other fields and to analyze it with reference to application to locomotive power plants.

It is also well to keep in mind that the progress aimed at by European development is toward a somewhat different goal than is desirable for this country. Thus the main advantage to be expected from high-pressure steam locomotives in this country is an increase in power capacity relative to locomotive weight, while in Europe the chief end is a reduction in fuel bills. To a certain extent both of these features are related as are also the other cost factors involved, such as maintenance, labor, and reliability.

One of the principal objections to the present type of locomotive is the potential destructive force inherent. All development should be with a view of increasing safety, and should aim at a final elimination of any danger from boiler explosions.

An economic success in the use of high steam pressures up to 1400 lb. per sq. in. has been already attained where the conditions have been favorable. Troubles encountered are found to be of the same order as for lower pressures. They have been due primarily to defects in furnace, combustion equipment, boiler, and auxiliary apparatus. Some defects that were of minor importance at low pressures have proved to be major items at high pressures. In all cases where standard or near-standard types of boilers have been used for high pressures the safety factor with reference to burned tubes has been found as reduced. The use and proposed further use of high pressures has led to considerable research work aimed at determining the physical characteristics of steam at high pressures and temperatures, and the reactions of

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[5] Consulting Engineer, New York, N. Y.

metals under stress at high temperatures. The extended tests on steam undertaken by the A.S.M.E. have not been completed as yet. As far as they have been carried they show only minor variations from former tables, calculated from miscellaneous tests.

With regard to metals a new theory has been developed—namely, that there is a continuous creep in all metals under stress at any temperature. This theory has not been proved as yet. Even if proved true for certain alloys or for certain temperatures it may still not apply to homogeneous metals, other alloys, or at all temperatures. It will undoubtedly be several years before this theory can be conclusively investigated. Its probability is, however, sufficient to warrant its consideration when designing equipment that will be exposed to high temperatures.

Experience With Boilers in Stationary Plants

Almost all of the high-pressure boilers now operating in the United States or being installed are of standard type, though somewhat modified in detail and arrangement. As before stated troubles experienced have been of the same order as for lower pressures. Increased care in maintaining a feedwater free from all impurities, slightly alkaline, and free from air has in some cases been sufficient to reduce maintenance to a negligible item. In other cases changes in furnace and combustion equipment have been required to reduce burning of tubes. With some installation changes in circulation have been made with good results. In all cases, however, though the improved efficiency has overshadowed the troubles experienced, the safety factory against burning of tubes has been materially reduced.

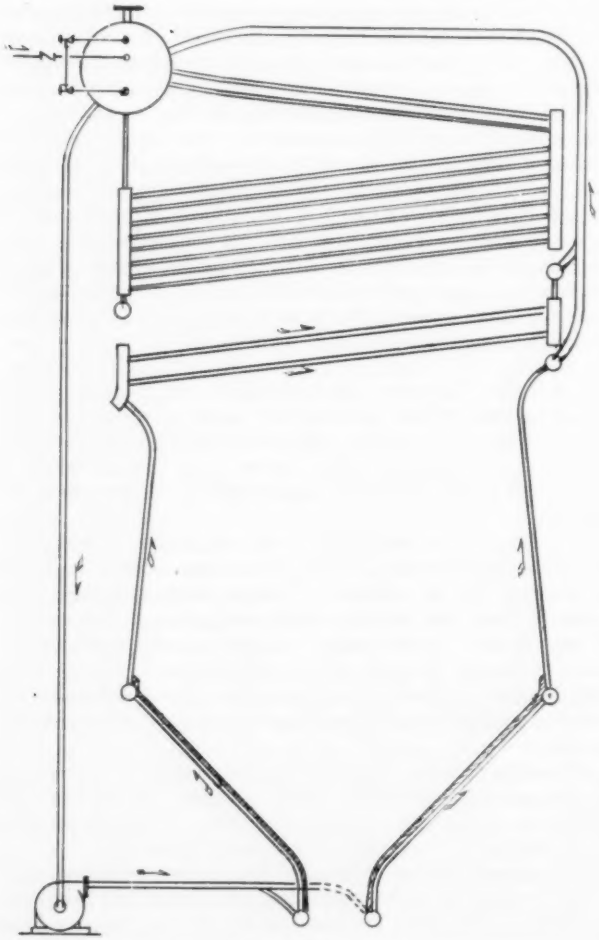


Fig. 6 Standard Type Boiler With Forced Circulation for Water Walls

In Europe high-pressure installations have been generally with special types of boilers. All the types used have complications that will apparently limit their field of usefulness even if they should be developed to achieve low operating maintenance costs.

One type, the Benson boiler, is a straight flash boiler operating above critical pressure. In other words, the flash point is removed outside the boiler proper. Where the steam is to be used at, say, 1600 lb. pressure, the extra power required for pumping against something over 3000 lb. is a considerable item. The Schmidt boiler uses an indirect heating effect. Distilled water heated to steaming temperature by the furnace is condensed in coils contained in the boiler drum. This boiler is evidently intended for use where the feedwater is dirty. The pressure of the steam produced is limited, since it must be well below the pressure of the steam in the closed circuit.

The indirect heating effect of this boiler renders it very expensive without any advantage over standard-type boilers where the feedwater is clean. Other defects are the very low velocity of circulation and a tendency for the capacity to fall off if the heating coils in the drum become coated.

The Loeffler boiler is an adventure into high temperatures, since steam is used to carry the furnace heat into the boiler drums. Forced circulation of steam is used through coils exposed to the furnace heat. Early small installations were more successful than the writer would have expected. Reports of larger installations indicate high maintenance costs. All of these special types of boilers are difficult to repair in case of trouble and, judging from the designs published, cannot be cleaned or inspected thoroughly.

Circulation of Steam and Water in Boilers

Velocities of natural circulation within any standard type of boiler reduce rapidly as the operating pressure is increased. Also there is a further tendency to reduce velocities of circulation due to the use of smaller tubes at high pressures. As to what velocities are attained in present practice or what are required, there is a wide divergence of opinion. Numerous velocity tests have been made. Even those tests made with the most care cannot be considered as more than approximately correct for the special conditions involved.

At pressures of, say, 200 lb. the velocities of flow are very high at high ratings, running up to over 40 ft. per sec. as the tube inclination approaches the vertical and with types where the flow resistance is low. At 1400 lb. pressure there would be a reduction in flow velocity in the ratio of one to six compared to 200 lb. pressure.

More important on the side of safety than actual flow velocities where the same are not abnormally low are consideration of the probable interruptions to flow due to surging within the boiler, steam laneing, and the possibility of deposit on the inside of tubes.

Surges may be caused by sudden load changes, irregular feedwater regulation of flow, and in some cases where the design is unsuited to the loads carried, by excess steam formation in the tubes exposed to the radiant heat. Surges are apt to cause temporary reversed circulation, and in some cases they may interrupt the supply of water to the down-comer tubes. Surges are more to be anticipated in low-pressure boilers than at high pressures. At high pressures any interruption to circulation is dangerous.

Steam laneing will occur at low flow velocities along the heated sides of vertical tubes and along the top sides of horizontally inclined tubes. It is evidently more to be feared at high pressures than low, due to the lower prevailing flow velocities. Deposit

on the inside of tubes is of course non-existent with absolutely pure feedwater. In most plants there will be times when a certain amount of dirt or scale forming solids will get into the feedwater. At high pressures on account of low velocities there will be a greater tendency for any scale or dirt present to accumulate on the tube surfaces and at the same time a slight scale or deposit, that would do no damage at low pressures, is dangerous.

In view of the numerous troubles with water walls, especially at high pressures, some manufacturers are now providing forced circulation in accordance with the La Mont method, for this part of the boiler. This is apparently a step in the right direction, since in most cases water-wall circulation is naturally slow because of the form of connections used. For high-pressure boilers it would be preferable to extend the forced circulation. Thus in Fig. 6 is shown a standard type boiler with forced circulation provided for the water walls and slag screen. The forced-circulation system shown is independent of the natural circulation for the rest of the boiler. Thus the feedwater connection and steam outlet from the drum are standard.

This arrangement should keep the surfaces exposed to radiant heat cooler with high pressures. It would also tend to prevent scale formation on the hottest surfaces. The power reqiremen ts for the circulating pump should be very small to obtain a higher velocity flow than can be had with natural circulation at high pressures.

The arrangement shown in Fig. 6 while a step in the right direction can apparently be improved. Thus the heat absorption would be improved slightly by extending the forced circulation to the convection section of the boiler. In addition by paralleling the feedwater with the forced circulation the cooling effect can be increased and a safety factor added. In Fig. 7 such an arrangement is indicated. Provided the circulation pump should fail the feedwater flow would with some induced circulation normally keep the boiler surfaces free from burns provided the feedwater were clean.

Heat Storage in Boiler Drums

The drums of high-pressure boilers are the weakest part where standard construction is used. The thickness of metal required is very great since tube holes cut away much metal. As a result seamless forged-steel construction is required at a large expense. Furthermore with standard construction the question of heat effect on the shell is problematical. This later consideration has led to their being shrouded from the hot gases.

As a heat accumulator the drum plays just as important a part as at lower pressures. Approximately the same water storage volume would be required to give the same heat reserve for the same percentage drop in pressure. The amount of storage required to give steady operation or to take care of load fluctuations depends on the character of the load, the type of combustion equipment, and the effectiveness of the combustion-control equipment. Thus with stoker firing and a large extent of refractory walls more heat storage will be required to take care of load variations than with pulverized coal and water-cooled walls. With standard drums it would be excessively expensive to provide sufficient storage to take care of the extreme cases.

Aside from storage the drum furnishes the steam liberation surface or separation space. With high pressure the separating area and volume required is much less than with low pressure. Based on the relative size of steam bubbles and velocities of flow the surface area required for 1400-lb. pressure is only one-fifth of that needed at 200 lb. In reality standard boilers as normally constructed have only a small portion of their water surface effective as steam-liberation surface at maximum loads.

Consideration of the above features would indicate that standard boiler drums are incorrect practice for high pressures. The use of forced circulation would allow for a more logical arrangement of drums.

In Fig. 8 is shown a design with a circulation similar to that indicated in Fig. 7 but with the drum or drums outside the setting and in a vertical position. Also in the connection from the top header to the boiler drum there is placed a separator having a centrifugal effect. From this separator a connection conducts the separated water to below the low-water line of the drum. The steam connection to the drum should be made so that the drum head will act as a secondary separator. This arrangement would

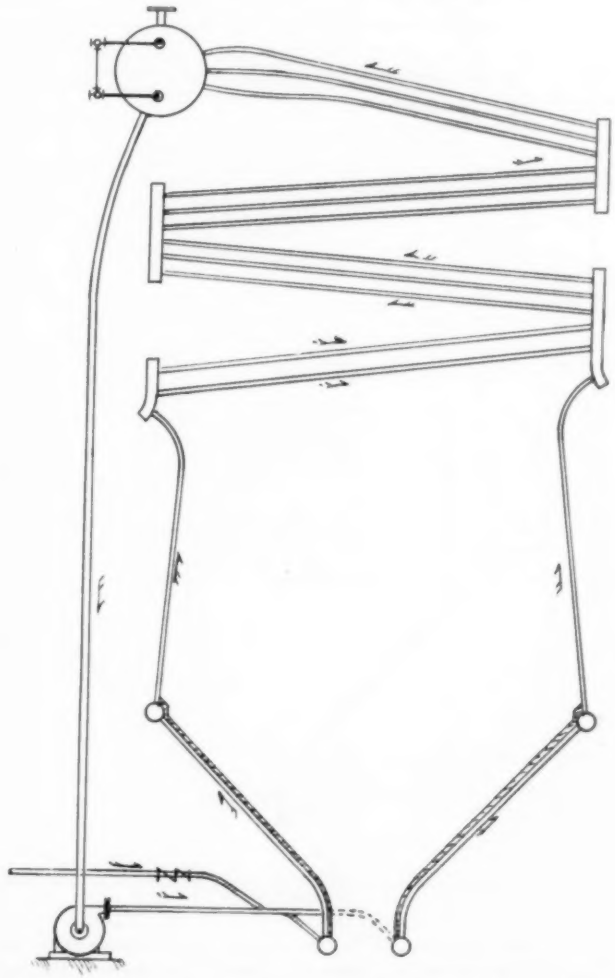


Fig. 7 Boiler With Feedwater Paralleled With Forced Circulation

allow for a considerable increase in storage volume relative to drum volume. Normally steam storage if required in excess of the drum-head volume should be provided near the source of steam usage. Thus the volume in the drum above the water line would be determined by the separating effect required. In an arrangement of this type it would also be desirable to increase the height of water-line variation, say to 3 or 4 ft.

With drums as shown the connections can be made so as not to weaken the shell. Thus the weight of metal required would be a minimum for the diameter and pressure. Where large storage is desirable or very high pressures used several drums can be connected up in multiple so as best to suit the storage or pressure requirements. The use of the separator in front of the drum provides a convenient method for removing the solids, where

dirty water will be used occasionally. Thus the water connection could be run through a pocket provided with a continuous blowdown connection.

An examination of the boiler outlined in Fig. 8 shows it to be in effect a flash boiler with storage and a supplementary recirculation superimposed. With the velocity flow greater than for standard high-pressure designs it is obvious that the heat-absorption rate will be increased per unit of surface for the same furnace temperature and velocity of gas flow through the boiler. Since the main resistance to heat flow is from the gas to the tube metal the total heat absorption is actually not markedly increased by the increasing rate of flow. This accounts for the fact that boilers with high circulation velocities are not materially more efficient than those with much slower rates of flow. The second largest resistance to the heat flow is from the metal to the water. Provided the metal were continually in contact with moving water this part of the resistance to heat flow would be materially less. As the rate of steam generation increases this later resistance increases. For high-pressure forced circulation with its higher continuous velocities of flow would reduce this resistance. It is, however, probable that a further large reduction in this resistance can be attained.

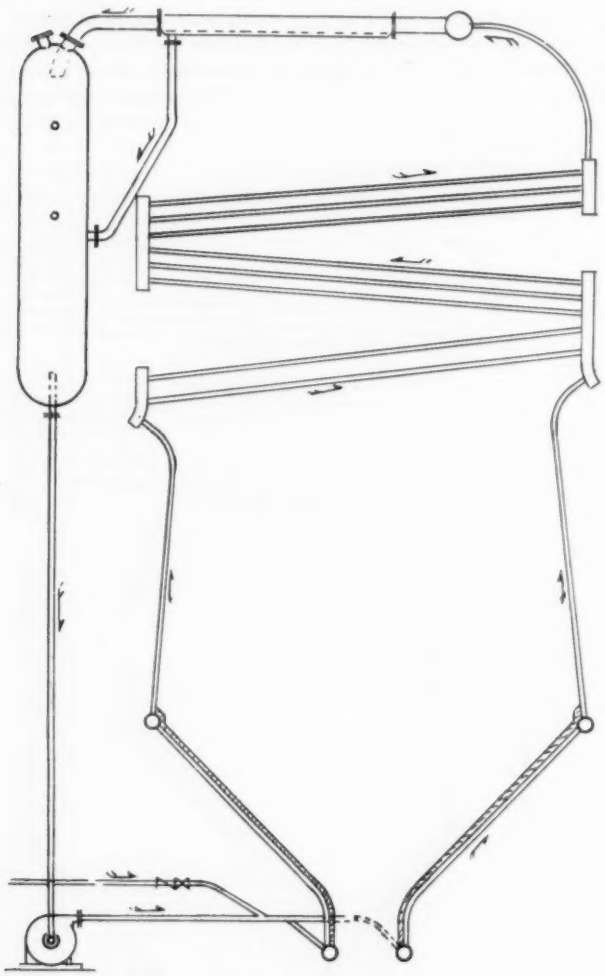


FIG. 8 BOILER WITH DRUM OUTSIDE THE SETTING IN A VERTICAL POSITION

In various heat exchangers twisted plates or spiral coils have been used to increase the heat-exchange effect for an equivalent pressure drop. Where the conditions have been favorable and the design correct considerable gains have resulted. Formerly when all boilers were designed for use with dirty water and a natural circulation it has been rightly deemed inadvisable to clog the internal-flow areas of boilers in any way whatsoever. With forced circulation and with practically absolutely clean water required for high pressures it seems proper to consider what advantages could be realized and the probable effect of an induced centrifugal flow. With the mixed vapor and fluid content it is apparent that centrifugal flow would force the fluid against the tube walls or in the place it is desired.

It would thus wipe off steam bubbles from the heating surface and prevent the formation of a lagging water film. On account of the fact that the largest resistance to heat flow—namely, from the gas tube—still remains, it is doubtful just how much the heat absorption would be increased. (Tests of the revolving elements of the Atmos boiler indicate a large gain.) It is certain that a decided increase in the safety factor relative to burns would be attained. In fact, it seems possible in this way to obtain a boiler free from any danger of burning as long as the feedwater was maintained reasonably clean. There is a further advantage of a gyratory circulation in that all surfaces of the tube inside would be kept wet whether the tube were vertical, inclined, or horizontal, and whether the flow was upward or downward through the tube.

One form of spiral core is shown in Fig. 9. This core would allow a clear opening through the center and would be clear of the tube surface. Thus there would occur in the center a direct flow of the steam and the swirling water would wipe the surfaces and carry along any contained solids. To obtain the best results from the use of such a core, tests should be run to determine the proper pitch and size for each design of boiler. It seems certain that with the gyratory effect increased heat absorption and at the same time a reduced pressure drop through the boiler could be achieved.

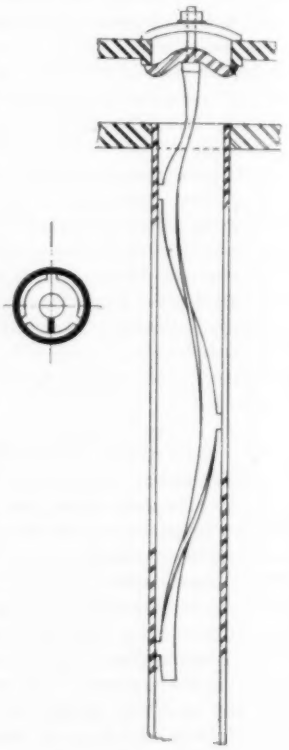


FIG. 9 SPIRAL CORE

With stationary plants where load variations are due to external causes and thus where automatic combustion control must start subsequent to the load change, heat storage is necessary for satisfactory operation. This would also be true where a large bulk of incandescent fuel or refractories are present in the furnace. On the other hand, with locomotive power plants, where a liquid or pulverized fuel is used and where the large load variations are operatively determined, large heat storage is not needed and may often be a detriment to good operation. For in this case pre-regulation of combustion control combined with the rapid response of a flash boiler to changes in combustion intensity should suffice to take care of large load changes. With small load variations only nominal heat storage is required. A properly designed flash boiler and combustion control should have ample. Where, however, there is probability of having to operate for intervals with dirty water a small storage with recirculation

effect should be added to prevent scale or deposit lodgment on the tube surfaces during low loads. Normally it would be so advantageous for locomotive power plants to eliminate extra storage that it would seem advisable to provide for always operating with clean feedwater.

In Fig. 10 a sketch of a flash boiler is shown. Since the economizer, superheater, and boiler sections proper are all parts of one heat absorber in the case of a true flash boiler they are included in the sketch. This arrangement assumes the use of cores in the boiler sections. It is probable that they should be used in the superheater also.

In connection with the construction of such a boiler as is indicated in Fig. 10 as well as for all high-pressure boilers, it is pertinent to state that all tubes, drums, and headers should be placed, built, and arranged so that they can be internally cleaned, inspected, and replaced without displacing or altering other parts of the boiler.

Combustion Control

At present there is no combustion control equipment used with or suited to locomotive power plants. There are, however, two factors that render its application to them easier than for central stations. The first is the possibility of allowance for pre-regulation as noted before. The second is that normally a much higher draft drop through the heating surfaces is used. On account of the latter characteristic a more positive force is available for regulation. Thus there are stationary plants operating very satisfactorily with automatic combustion control where the draft drop through the heating surfaces varies only from 0.05 in. to 0.8 in. water pressure per square inch for a load variance of 50 per cent to 300 per cent. With a locomotive power plant the variance in draft drop would probably have to be made at least 5 in.

There are different methods by which pre-regulation can be obtained. One would consist in operating during stand-by and while driving at different pressure ranges. For illustration, consider a master controller suited for regulation either between 1225 and 1175 lb. pressure or between 1250 and 1200 lb. Standing by, with only auxiliaries running, the master controller would be set to control combustion between 1175 and 1225 lb. On starting to drive opening of the throttle would first change the master controller's pressure range to between 1200 and 1250 lb. Thus the combustion intensity would be increasing as the throttle valve opens.

On stopping or throwing off of load the reverse procedure would be followed. One form of emergency overloading would need to be guarded against for locomotive plants—namely, wheel slippage. To take care of this and to prevent any excessive boiler pressure drop either an auxiliary automatic throttle valve or attachment on the main valve should be installed to close off gradually in case of excessively low boiler pressures. Any such arrangement should be provided with compensating and dampening effect.

Feedwater-Flow Control for Flash Boiler

In the past one of the main troubles experienced with flash boilers and one that especially prevented their use in large sizes was the failure of the automatic controls provided. Combustion control was not understood at the time and the methods tried were defective in principle and design. At present the requirements are fairly well understood and there should be no trouble in developing suitable equipment.

With the small flash boilers in use and formerly tried out two methods of automatic flow control have been used. One is regulating the feedwater flow by the boiler pressure and the other by the temperature of the out-flowing steam. The latter method apparently is the correct way for large sized units producing superheated steam. An analysis of possibilities would suggest the use of the saturated vapor pressure of mercury. It is possible that a direct regulator with a mercury generator in the steam outlet and a diaphragm-actuated flow valve could be evolved. This would, however, require careful consideration of relative volume, expansion, and temperature characteristics. A surer way would be to utilize the oil-pressure hydraulic system, required for the combustion control, to regulate the flow valve and feedwater-pump governor. Then the mercury-vapor pressure would only have to actuate a small four-way oil valve.

At first glance it appears that temperature regulation of flow control would act inversely to requirements. Thus on increase in loading, the pressure drops, coincidentally, the velocity of flow

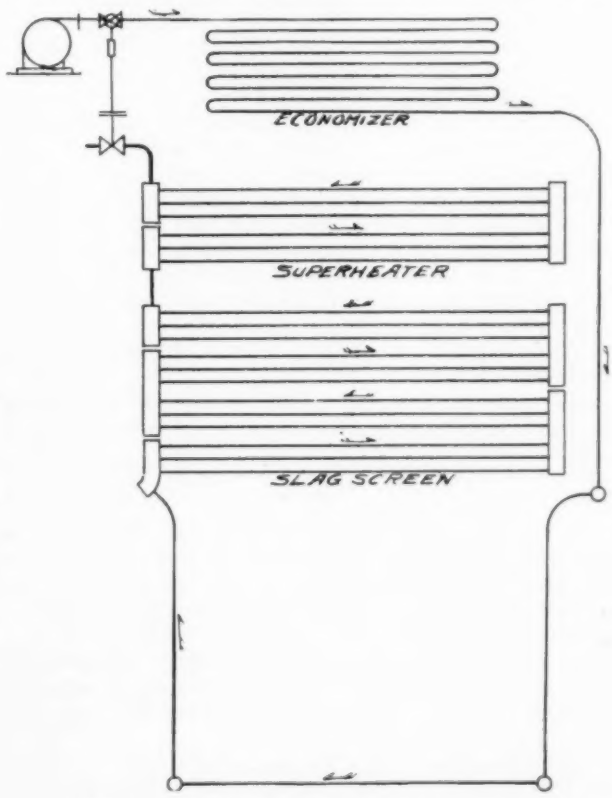


Fig. 10 Type of Flash-Boiler Construction

increases, both factors tend to drop the steam temperature and thus through the flow regulator to reduce the feedwater flow. Thus for a few seconds the increasing load is carried on stored or partially stored water. The control, however, would restore conditions to a balance before any possible damage could result. Meanwhile temperature control should insure a much closer adherence to a uniform temperature of steam than could be obtained where the steam temperature depended on many varying factors as with water-line control of feedwater.

With temperature-flow control the functions of the superheater, boiler, and economizer are interchangeable to a certain degree. Thus as the load increases the superheating section of the boiler decreases in extent, and steam formation will probably take place at an earlier point in the flow or in what would normally be the economizer.

On this account it would be impractical to provide temperature regulation of flow where any storage and recirculation effect is used.

Boiler Auxiliaries

Aside from the boilers high-pressure plants have experienced some troubles with boiler feed pumps. In some cases where hydraulic balancing was used it was found necessary to use special thrust bearings. This same trouble has often occurred to a less extent at lower pressures. In other cases there were minor troubles in keeping the high-pressure glands tight. A cure for both of these troubles would appear to be to use balanced-stage types of pumps with the stages arranged so that the lower pressure stages are on both ends.

Combustion

Experience of recent years has show more fully the feasibility of burning pulverized coal at the intensities requisite for use with the largest powered high-pressure steam locomotives where a fair efficiency is attained. Experience has also emphasized the importance of providing fine pulverization, preheated air, slag screens, complete water walls, or water-cooled furnace walls, adjustable turbulent burners, and a positive automatic combustion control where high intensities and efficiency are aimed at. Compromises have proved futile.

Dangers feared from storing and handling pulverized fuel have not developed. However, for locomotive power plants it would be advisable to eliminate all danger by storing in an atmosphere of CO_2. This can easily be drawn off from the fuel gas through a separator and a small amount constantly forced into the storage space. The storage compartment should then only be vented at the top through a seal. With a straight flash boiler pulverized coal or oil would of course be required. When supplementary storage and recirculation are added to the boiler, stoker firing can be used. Suitable automatic combustion control should always be used.

Drive

For stationary high-pressure plants both turbines and engines have proved satisfactory on the score of reliability and efficiency. Troubles encountered have been few and easily remedied where suitable materials have been used and where the temperatures have not been excessive.

With locomotives high-pressure engine drives with atmospheric exhausts have been used, and are showing up well as far as reliability is concerned. The types used have not been such as to attain a good machine efficiency.

The turbine drives used on locomotives have mostly been standard pressure, condensing with gear transmission. The efficiencies at high speed have been fairly good. Apparently the maintenance of the gears and the unsuitable characteristics of the variable-speed turbine will always limit this type of drive to a few special services and conditions.

Electric transmission, with Diesel-engine-driven locomotives and for marine service with turbine drive, has shown an all-around economic superiority over gear transmission. For turbine-driven steam locomotives the superiority of electric over gear transmission should be even more pronounced.

At present it appears that for large locomotives the combination high-pressure direct-acting compound engine with a low-pressure turbo-generator drive promises the best economies. For smaller units a compound engine drive with the high-pressure cylinder of standard type and the low-pressure cylinder a modified uniflow construction would show fair efficiency and low first cost. Complete turbo-generator electric drive while more expensive and not as efficient as the combination drive would suit many conditions better. It would have better acceleration than complete engine drive and could be arranged for operation from a trolley over electrified zones.

Condensers

In high-pressure steam locomotives provided with an efficient regenerative heating effect the size of the condenser required would be much smaller than for standard-pressure locomotives. At the same time the desirability of condensing effect is greater with high pressure due to the necessity of a clean feedwater for the boilers.

Present condensers used on locomotives have been fairly successful in producing condensing effect. They are at the same time too bulky and expensive to warrant the assumption that they are a successful solution. The writer has analyzed the problem and is convinced that an evaporative condenser with forced air circulation and cooling sprays located near the front can be built to give a fairly high vacuum.

Two designs have been sketched out for a 28,000,000-B.t.u. cooling effect with a 24-in. vacuum at 70 deg. temperature and 60 per cent humidity. The surfaces were based on a heat transmission derived from various tests on indirect hot-air heaters, automobile steam condensers, and some early evaporative condensers. There are no tests that would apply closely to the conditions involved. With the assumptions taken the volume requirements would be very small relative to types of condensers used for locomotives. In addition the first cost would be even smaller in ratio due to the simplicity of a direct effect. The essential details work out so as to provide amply for steam flow, air flow, expansion, and structural strength. Placed at the front of the locomotive the power required for the fan would be small during most periods of operation. With low temperatures or low loads very little condensing water would be required. At freezing and below, fair vacuums could be maintained without any condensing water. At high temperatures there would be little reduction in the vacuum obtained due to the large increase in evaporative effect for a small temperature rise. Spray and fan operation could easily be made to regulate automatically from the condenser pressure. Apparently the probable advantages of this type of condenser are so great that a thorough trial would be justified.

Oil Separation

With cylinder drive and condensing effect a separation of the cylinder oil is required. With stationary plants large gravity-type separators when properly designed and of suitable size have proved satisfactory. With locomotive power plants there is not sufficient space to use this type.

For pressures above atmosphere there are one or two designs of centrifugal separators that will remove most of the oil and moisture from the steam. At condenser pressures they are not so efficient. There is one design of separator with a revolving core that would be especially efficient with an outside drive that would maintain at all times the proper speed for maximum separation.

In addition to any separation used, filtration should be provided. There are several filtration mediums that will clean the water of all oil as long as they are kept clean or the filterant replaced at frequent intervals.

Conclusion

At the present time the writer feels that progress toward high-pressure steam drive for locomotive power plants is tending in the direction of exploitation of special patented devices combined with a retention of undesirable features of standard practice.

Most of the experience and knowledge are now extant which if combined could produce a safe high-pressure steam locomotive that would give a real all-around economy without adventuring in excessive temperatures or dangerous conditions. Such further knowledge as is required can be obtained at a reasonable cost and with a small effort. Offhand statements as to practicability or vice versa are of no value.

RR-52-6

High-Pressure and High-Temperature Steam for Locomotives

By C. F. HIRSHFELD,[1] DETROIT, MICH.

The author states his position as that of giving to railroad men the benefit of experience had in stationary steam-power-plant practice and not as that of telling them what to do in locomotive practice. The advantages of high pressures and temperatures in stationary practice are considered separately for condensing operation and for back-pressure operation, respectively, and the differences are stressed. Certain experiences and observations regarding the behavior of metals and the boiler circulation under extreme conditions are given, and these are followed by speculations regarding the possible lines of development of locomotives.



LET me start this paper by making several statements having nothing to do with high steam pressures and temperatures.

First, I know practically nothing about steam locomotives in the sense in which railroad men know about them;

Second, I have great respect for the engineers who have developed the steam locomotive to its present state; and

Third, I am not presumptuous enough to believe that I can teach such men anything about that which they know so much about and with respect to which I know so little.

With such an introduction one might well inquire why I present this paper. To be perfectly frank, it does not result from any spontaneous ebullition of ideas insistent upon being disclosed to the world at large or to a particular group in that world. It was asked for by your Division, apparently in the belief that one familiar with modern developments in stationary steam practice might be able to bring you useful thoughts and experiences from that field. I recognize this as a possibility and, remote as it may be, it must serve as my excuse.

Some thirty-odd years ago the stationary-plant engineer began a march of progress which probably represents one of the most remarkable advances ever made in a like period. It happens that my life in the capacity of wage earner started at about the beginning of this period, and that a teaching experience of some years caused me to become familiar with the history of power-plant engineering in the preceding period.

The combination has often led me to contrast mentally the radically different rates of progress and to speculate as to the cause of such differences. At first I saw the cause in the development of this or that piece of equipment, but I have finally come to realize that the basic cause was a change in the outlook of the human beings who served as leaders. I am convinced that when the progress of stationary-plant engineering during the first third of the present century is viewed in retrospect, the most striking characteristic will be found to be the willingness of the leaders to cut loose from the past and to try new things, to strike out boldly into unexplored fields.

Looking at the steam locomotive through the eyes of an engineer who has concentrated his efforts in the stationary field, I am struck by the fact that it appears to have improved little during the period in which my own field of endeavor has made such rapid progress. To be sure, it has been made bigger, superheaters have been adopted, feedwater heaters have been added, and so on, but the locomotive that I viewed with wonder as a small boy and the locomotive that I view more understandingly as a middle-aged man are essentially the same.

Now of course this might be due to the fact that the locomotive of my youth was already so well developed that no further improvement of a basic or fundamental type could be made. Or, it might be due to the fact that after reaching that stage in the development of this device its designers became conservative, refused to make radical departures and contented themselves with improvements of a minor character. Or again, it might be due to the fact that the railway industry did not require any more radical changes to enable it to operate satisfactorily under the economic conditions which have existed. Admittedly, I am not sufficiently skilled in this particular field to enable me to judge. However, I sense the fact that the second and third explanations are probably the correct ones, with most of the weight upon the third.

Basic Changes in Locomotive Design Apparently Necessary

If one may judge from the presently evident movements in the field, the economic conditions have altered to such an extent that basic changes in locomotive design are felt to be necessary. If this be the case, designers will have to bestir themselves and acquire a new point of view. No longer will it be sufficient to improve by whittling here and adding there. It will be necessary to consider the whole problem *de novo*, to depart temporarily from all the traditions of the past, to let the imagination have free rein in team with analytical ability. What will evolve may possibly be guessed at; it certainly cannot be predicted.

It is natural that in considering any radical change from past practice, designers should give thought to what has happened in more or less parallel fields, as for instance in that of the stationary power plant. Such developments may or may not be applicable to the plant required to move about as does a locomotive, but the facts cannot be determined except by analysis and possibly also by experiment.

When the locomotive designer begins to study recent stationary-plant development he discovers marked increases of steam pressure during a comparatively short period, and latterly a very evident tendency toward radical increases of steam tem-

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Contributed by the Railroad Division and presented at the Annual Meeting, New York, N. Y., Dec. 1 to 5, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

perature. It is but natural to ask whether these are proper items for serious consideration in his field of endeavor.

In stationary practice there are two radically different conditions leading to the use of high steam pressure. The first is the higher thermal economy obtainable in condensing plant. The second is the greater quantity of power obtainable from steam expanded in engine or turbine and then exhausted, at pressures near or above atmospheric, for process or heating purposes. Such reasons have underlaid an increase of average steam pressure from about 180 lb. gage in 1900 through 200 lb. gage about 1913 to about 450 to 500 lb. gage today with increases to 1400 and

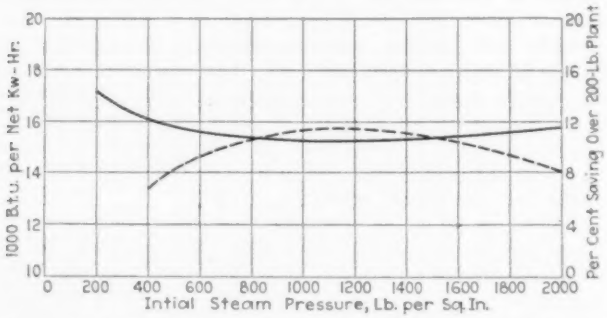


FIG. 1 SOLID CURVE SHOWS STATION HEAT RATE, RANKINE CYCLE, NO REGENERATIVE FEED HEATING, STEAM AT 700 DEG. FAHR. BROKEN CURVE SHOWS PER CENT SAVING OVER 200-LB. PLANT

1800 lb. in a few exceptional cases. The average steam pressure in representative locomotives is today about 220 lb. gage, with a pressure of about 280 lb. as the highest normal value. Higher pressures are in use, but may still be regarded as more or less experimental. The figure of 280 corresponds to the value reached in stationary practice in exceptional cases about fifteen years ago, and in very common use about eight to ten years ago. I can still remember very vividly the shaking of heads that accompanied the first increases above that value.

BELIEF THAT THERMAL ECONOMY INCREASES INDEFINITELY WITH INCREASING STEAM PRESSURE ERRONEOUS

There is a popular belief that thermal economy increases indefinitely with increasing steam pressure and this belief has been responsible for quite a bit of loose thinking. Comparatively simple calculations suffice to show that it is erroneous.

The thermal economies obtainable with various steam pressures and temperatures in condensing operation are shown in a convenient way in Table 1. In preparing this table certain assumptions were required; it is not believed necessary to recite them here, suffice it to say that they were so made that the figures given are directly comparable, and that these figures give conservative values for well-operated turbine equipment of moderately large size.

A brief survey of these figures will show what appear to be extraordinarily good performances for low-pressure, low-temperature plants. The figures are believed to be approximately correct in this respect. They reflect the fact that during the progress to higher pressures and temperatures we have made other improvements in plant design. If these improvements were carried back to the low-pressure plant, the performance of the latter would be much better than the performances mentally associated with such pressures. This is a fact which should not be overlooked; at least a good part of the credit that has been given popularly to higher steam pressures in modern plants belongs properly to improved plant design.

For the purpose of indicating both the thermal advantages and limitations of higher pressures and temperatures in condensing operation, a few numerical relations will be considered. Take, for example, the decreased heat consumption resulting from the increase of pressure at a given temperature and using the Rankine cycle, that is, without regenerative heating. These values, taken from Table 1, are plotted in Fig. 1, using steam at various pressures but at a single temperature, namely, 700 deg. fahr. As a matter of fact the curve is partly non-realizable because beyond about 500 lb. initial pressure the water content of the steam at and near exhaust pressures would become too great to be economically usable with available turbine equipment. It is at once apparent that the great improvement with increasing pressure occurs in the lower ranges for such conditions as are indicated in Fig. 1, and that there is a reversal, that is, an actual loss if the pressure is carried high enough. It is questionable whether any pressure higher than 500 to 600 lb. could be justified for such conditions. A higher initial temperature would alter the conditions slightly. With an initial temperature of 1000 deg. fahr. there would be a continuous improvement up to and including 2000 lb., but the total reduction in passing from 1000 to 2000 lb. would be only 350 B.t.u. as against almost 2000 B.t.u. in passing from 200 to 1000 lb.

A great part of the saving that is achieved through the use

TABLE 1 THERMAL PERFORMANCE OF CONDENSING TURBINE PLANT

Steam pressure, lb. per sq. in. abs.	Steam temperature, deg. fahr.	Station heat rate, B.t.u. per net kw-hr. — Rankine cycle (no regenerative heating)	Regenerative cycle — 1-stage feed heating	2-stage feed heating	3-stage feed heating	4-stage feed heating
200	700	17,170	16,230	15,980	15,840	15,760
200	800	16,420	15,590	15,330	15,220	15,120
200	900	15,800	15,000	14,740	14,630	14,560
200	1000	15,220	14,460	14,230	14,120	14,030
400	700	16,030	15,050	14,770	14,610	14,490
400	800	15,370	14,460	14,200	14,040	13,940
400	900	14,770	13,920	13,680	13,530	13,440
400	1000	14,240	13,450	13,220	13,090	13,000
600	700	15,580	14,520	14,230	14,070	13,960
600	800	14,900	13,930	13,660	13,500	13,390
600	900	14,320	13,420	13,170	13,020	12,920
600	1000	13,800	12,970	12,730	12,590	12,500
800	700	15,360	14,250	13,940	13,770	13,650
800	800	14,640	13,620	13,340	13,170	13,060
800	900	14,050	13,110	12,840	12,690	12,590
800	1000	13,530	12,650	12,410	12,260	12,170
1000	700	15,240	14,080	13,760	13,570	13,450
1000	800	14,480	13,420	13,120	12,950	12,840
1000	900	13,380	12,910	12,630	12,470	12,360
1000	1000	13,350	12,440	12,190	12,040	11,940
1200	700	15,210	14,000	13,670	13,490	13,370
1200	800	14,420	13,130	13,010	12,840	12,730
1200	900	13,760	12,750	12,460	12,310	12,200
1200	1000	13,210	12,270	12,010	11,870	11,770
1400	700	15,270	14,010	13,670	13,490	13,360
1400	800	14,360	13,230	12,910	12,750	12,630
1400	900	13,690	12,660	12,370	12,210	12,110
1400	1000	13,120	12,160	11,890	11,750	11,660
2000	700	15,780	14,300	13,910	13,710	13,560
2000	800	14,500	13,260	12,920	12,760	12,620
2000	900	13,610	12,520	12,220	12,040	11,930
2000	1000	13,000	11,990	11,710	11,570	11,470

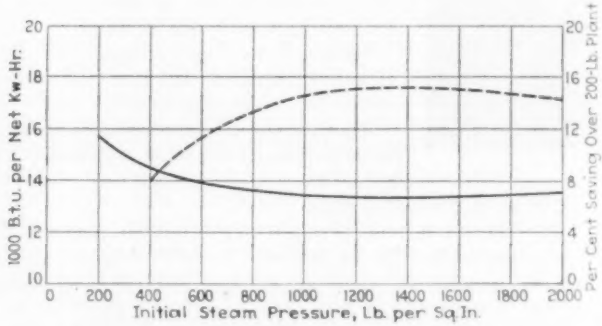


FIG. 2 SOLID CURVE SHOWS HEAT RATE WITH FOUR STAGES OF REGENERATIVE FEED HEATING AND STEAM AT 700 DEG. FAHR. BROKEN CURVE SHOWS PER CENT SAVING OVER 200-LB. PLANT

TABLE 2 THERMAL PERFORMANCE OF NON-CONDENSING TURBINE PLANT; LARGE TURBINES EXHAUSTING AT 5 LB. GAGE

Steam pressure, lb. per sq. in. abs.	Steam temperature, deg. fahr.	B.t.u. per net kw-hr.	Net kw-hr. per 1000 lb. steam supplied
200	700	32,500	46.3
200	800	31,250	51.3
200	900	29,750	56.3
200	1000	28,000	60.8
400	700	26,750	56.0
400	800	25,650	62.3
400	900	24,650	68.3
400	1000	23,500	73.4
600	700	24,500	60.0
600	800	23,250	66.7
600	900	22,400	73.2
600	1000	21,250	78.7
800	700	24,000	60.5
800	800	22,500	68.5
800	900	21,650	75.5
800	1000	20,500	82.2
1000	700	23,900	60.4
1000	800	22,250	68.7
1000	900	21,200	76.4
1000	1000	20,000	84.5
1200	700	23,900	60.0
1200	800	21,850	68.9
1200	900	20,850	77.0
1200	1000	19,650	86.2
1400	700	24,200	59.2
1400	800	22,000	68.7
1400	900	20,750	77.4
1400	1000	19,400	87.0
2000	700	27,550	49.0
2000	800	22,500	65.0
2000	900	20,750	75.7
2000	1000	19,200	87.0

of high-pressure steam in condensing stationary practice is achieved through the use of regenerative feedwater heating. The higher the pressure, the greater the effect of this process. Thus, using figures from Table 1, the saving resulting from regenerative heating in four stages at 200 lb. and 700 deg. fahr. is 1410 B.t.u., whereas at 2000 lb. and 700 deg. fahr. it is 2274 B.t.u. However, even with regenerative feedwater heating,

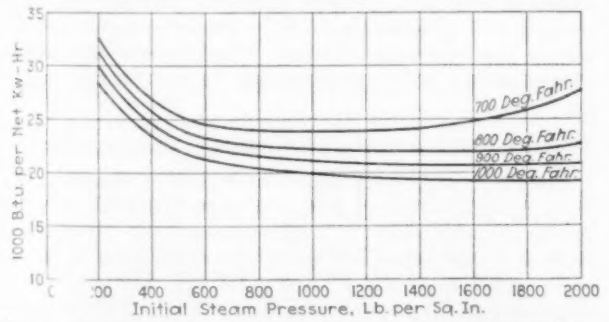


FIG. 3 STATION HEAT RATES FOR VARIOUS INITIAL STEAM PRESSURES AND TEMPERATURES. 5 LB. PER SQ. IN. BACK PRESSURE. FEEDWATER HEATED TO 212 DEG. FAHR. LARGE TURBINE PLANT—(20,000-KW. UNITS)

the gains obtainable with like pressure increments become increasingly smaller as the pressure increases and ultimately reverse. This is shown in Fig. 2, which corresponds to Fig. 1. Comparison of the percentage curves of the two figures will show the effect of regenerative feed heating in increasing the saving resulting from increased steam pressure.

Inspection of these curves indicates that at 700 deg. fahr. there is probably little justification in exceeding about 600 lb. without regenerative heating and something like 800 to 900 lb. with four-stage regeneration, unless reheating be resorted to. In practice the limits are set in both cases close to 500 lb. because of the serious effect of condensate in the steam. The situation is naturally improved by increasing the initial temperature. If 1000-deg. fahr. steam could be used, the practical or commercial upper pressure limit without reheating would probably be in the neighborhood of 1000 lb.

THE QUESTION OF STEAM CONDENSING LOCOMOTIVES

The question of whether condensing operation is possible or desirable with steam locomotives appears to be unanswered as yet. If the experiments that are now being made with condensing turbine-driven locomotives should prove such construction to be commercially feasible, the figures just given may serve to indicate the extent to which steam pressure may be profitably carried when viewed with respect to thermal considerations only.

There are, however, other considerations which may also be weighty, particularly in the case of locomotives. Thus, for example, high-pressure steam occupies much less space per unit of weight than does saturated steam. One pound of steam at 200 lb. absolute and 700 deg. fahr. occupies a space of 3.4 cu. ft., whereas the same weight at the same temperature, but at a

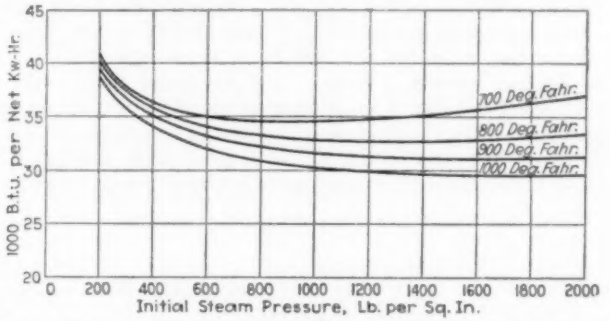


FIG. 4 STATION HEAT RATES FOR VARIOUS INITIAL STEAM PRESSURES AND TEMPERATURES. 5 LB. PER SQ. IN. BACK PRESSURE. FEEDWATER HEATED TO 212 DEG. FAHR. SMALL TURBINE PLANT (2000-KW. UNITS)

pressure of 1400 lb., occupies only 0.4 cu. ft. As a result of this fact, pipes and other parts for high-pressure steam may in fact weigh less than for the equivalent amount of low-pressure steam. Many peculiar effects follow from this and other characteristics of high-pressure steam, and it is almost certain that the thermal savings will not be completely determinative.

When non-condensing operation is considered we obtain an entirely different sort of picture from that disclosed above. I

TABLE 3 THERMAL PERFORMANCE OF NON-CONDENSING TURBINE PLANT; SMALL TURBINES EXHAUSTING AT 5 LB. GAGE

Steam pressure, lb. per sq. in. abs.	Steam temperature, deg. fahr.	B.t.u. per net kw-hr.	Net kw-hr. per 1000 lb. steam supplied
200	700	40,650	37.1
200	800	40,000	39.3
200	900	39,250	41.8
200	1000	38,750	44.2
400	700	36,250	41.2
400	800	35,750	44.0
400	900	35,000	47.0
400	1000	33,900	50.3
600	700	35,000	42.5
600	800	34,000	45.9
600	900	33,250	49.0
600	1000	32,000	53.2
800	700	34,500	42.5
800	800	33,250	46.5
800	900	32,250	49.7
800	1000	31,000	54.7
1000	700	34,500	42.2
1000	800	32,900	46.6
1000	900	31,750	50.0
1000	1000	30,250	55.5
1200	700	34,750	41.5
1200	800	32,750	46.5
1200	900	31,350	50.3
1200	1000	29,900	56.0
1400	700	35,200	40.5
1400	800	32,750	46.2
1400	900	31,250	50.5
1400	1000	29,700	56.3
2000	700	37,000	36.5
2000	800	33,400	44.3
2000	900	31,500	50.0
2000	1000	29,500	56.0

shall present it as it appears when considered with respect to industrial plants in which steam is exhausted for process purposes. You who are more familiar than I with the locomotive engine can translate my figures easily to the terms in which you deal.

Numerical values for this condition are given in Tables 2 and 3, and certain of the tabulated numbers and values obtained therefrom are shown in Figs. 3, 4, 5, 6, and 7. It should be noted that these values are developed for steam-turbine plant, and that large and small units, respectively, are considered. In reciprocating plant running under conditions of greatest economy the values would probably lie between those shown for the two sizes chosen.

Inspection of Fig. 3 shows the same sort of reversal in the 700-deg. fahr. curve that was noted for condensing conditions. With the highest initial temperature a continuous improvement is shown with increasing pressure. The really significant figures for non-condensing operation are those plotted in Figs. 5 and 6, giving the net output per 1000 lb. of steam expanded down to 5 lb. gage pressure. Even at the low initial temperature of 700 deg. fahr., Fig. 5, an increase of output of over 20 per cent is obtained from a given weight of steam by raising the initial pressure from 200 to 400 lb. It is particularly interesting to note the comparatively small gains resulting from increasing the

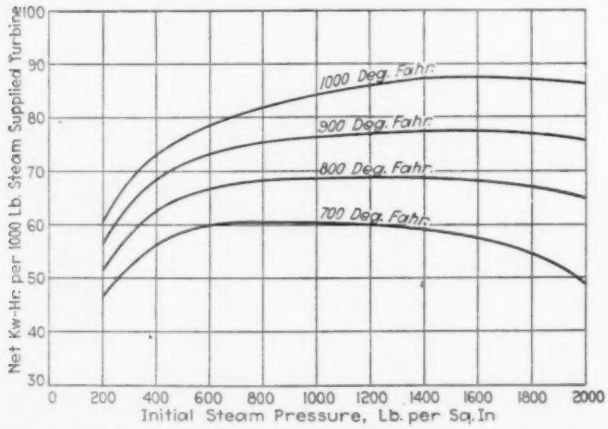


FIG. 5 NET POWER MADE AVAILABLE FROM A GIVEN WEIGHT OF STEAM AT VARIOUS INITIAL CONDITIONS AND 5 LB. PER SQ. IN. BACK PRESSURE. FEEDWATER HEATED TO 212 DEG. FAHR. LARGE TURBINE PLANT (20,000-KW. UNITS)

initial pressure above 800 lb., even at comparatively high initial temperatures.

DECREASE IN ENGINE SIZE WITH INCREASE OF PRESSURE

The curves given in Figs. 7 and 8 probably put this matter in somewhat more significant fashion for the locomotive designer. These curves show the decrease in "engine size" with increase of pressure. In this case this means area through the last set of blades and volume of exhaust casing. In the case of a reciprocating engine it would correspond roughly to piston displacement under conditions of minimum cut-off. It will be noted that the decreases in engine size are really significant, and it should be remembered that similar or greater decreases occur in all steam-carrying parts. It will also be noted that the greater part of the decrease is attained in most cases by the time a pressure of 600 to 800 lb. is reached.

It is at least conceivable that the combination of decreased fuel consumption per unit of output and the decreased volume might be used in locomotive practice in either one of two ways. One would be the increase of capacity without increase of grate area or its equivalent; the other would be decreased size of parts for present output. It would take much more technical knowledge of the field than I possess to evaluate the significance of such possibilities. I shall have accomplished my end if I have shown you that, even in such simple matters as thermal performance and output per pound of steam, the situation is highly complicated and requires detailed study; that it is quite erroneous to assume that improvement in these respects must necessarily follow increase of steam pressure or temperature.

It should be helpful to consider what may be expected if theoretical considerations along such lines as are suggested above

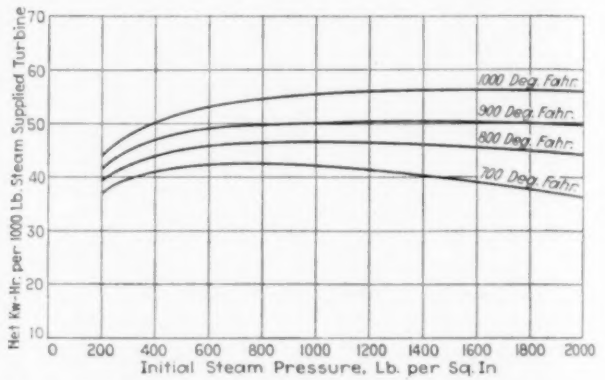


FIG. 6 NET POWER MADE AVAILABLE FROM A GIVEN WEIGHT OF STEAM AT VARIOUS INITIAL CONDITIONS AND 5 LB. PER SQ. IN. BACK PRESSURE. FEEDWATER HEATED TO 212 DEG. FAHR. SMALL TURBINE PLANT (2000-KW. UNITS)

should show that radical increases of pressure and temperature promise worth-while results in locomotive practice. Enough has been said to indicate that initial temperature is very closely bound up with initial pressure in turbine practice. The same thing is true to some extent in reciprocating-engine practice, even in non-condensing operation. Therefore the consideration of permissible initial temperature appears to be the logical starting point.

TEMPERATURE LIMITATIONS IMPOSED BY METALS AVAILABLE

Experience with steam superheated above a temperature of 750 deg. fahr. is still too meager to make it safe to draw final conclusions with respect to higher temperatures. At present it looks as though carbon-steel tubes can be used safely to produce steam with a temperature of 800 to 850 deg. fahr. provided the metal temperature does not rise too high. The limit in this respect is taken at present at about 950 deg. fahr. provided the steam is practically free of oxygen when it reaches the superheater tubes. It is also necessary to so design that the unit stresses in the metal do not exceed something of the order of 4000 lb. per sq. in.

The importance of oxygen-free steam cannot be ignored as experience indicates that very rapid attack upon the metal may be expected at such metal temperatures if any appreciable quantity of oxygen is present in the steam.

This is also the temperature at which reaction between iron and steam begins to become noticeable. As a matter of fact, this reaction does not occur to a sufficient extent at 950 deg. fahr. to be at all significant, but it becomes of great importance at between 1000 and 1050 deg. fahr. The reaction is such that a very closely adherent magnetic-oxide scale is formed on the steam side of the tube and hydrogen passes off with the steam.

Higher temperatures may be used with alloy steels such as the nickel-chromium alloys and others which show higher creep strengths than the carbon steels. Such metals have been used in experimental equipment delivering steam at 1100 deg. fahr., and there is no indication of short life due to creep, simple oxida-

tion, or reaction with steam. Unfortunately the available alloys are all very high priced, and their metallurgy and physical behavior are not yet well understood.

These facts would seem to indicate that we are limited to steam temperatures of the order of 800 to 850 deg. fahr. if restricted to carbon-steel tubing, and that we can probably extend this temperature to 1000 or 1100 deg. if the cost of the more expensive alloys can be justified. These figures immediately enable us to determine the highest steam pressures that show thermal advantages under any selected set of conditions. It must be realized, however, that the thermal considerations

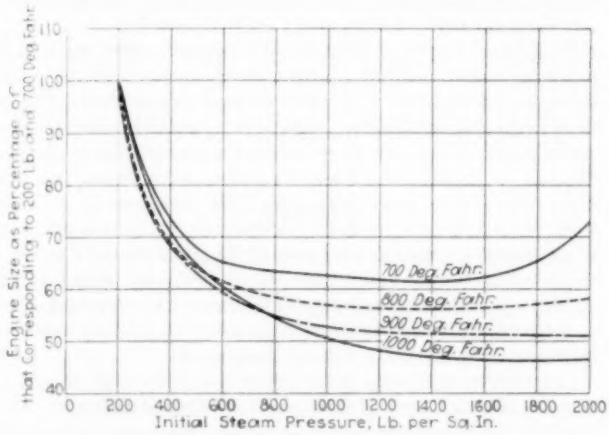


Fig. 7 Effect of Initial Steam Conditions on Physical Size of Engine. Large Turbine Plant. 5 Lb. per Sq. In. Back Pressure

alone are not completely determinative. There are many others of operating and economic character which are equally important, and much more difficult to evaluate with respect to any particular field.

Boiler Characteristics at High Pressures

If one chose about 800 deg. fahr. as the highest temperature which now seems reasonably possible under locomotive conditions, it would appear from thermal considerations as though a pressure in the neighborhood of about 800 lb. might be usable for non-condensing operation. It becomes pertinent to inquire into boiler characteristics at such pressures. Stationary experience with the higher pressures has been had with water-tube boilers exclusively, and with comparatively clean and pure boiler water. It is a long cry from such conditions to those found in average locomotive practice.

With properly designed water-tube boilers there has been no evidence of any intrinsic limitations to adequate natural circulation at pressures in the neighborhood of 600 to 700 lb., and there is no reason to expect such trouble at 800 lb. On the other hand, when pressures of 1200 to 1400 lb. are reached, the forces causing natural circulation appear to be approaching such magnitudes that very small changes of design or condition may lead to serious trouble.

In this country we have succeeded in obtaining commercially satisfactory operation at such pressures with water-tube boilers of what one may call conventional design, but it has required careful design and careful operation. European engineers, on the other hand, calculated in advance the forces that should be available for creating natural circulation, and concluded that somewhere in the neighborhood of 1200 to 1400 lb. one entered the questionable region. It is possible that this is responsible for some or all of the radically new types of high-pressure steam-producing equipment now being experimented with in Europe.

Speaking first in general terms, the temperature of saturated steam rises with its pressure. Thus, even though the metal surfaces be scrupulously clean on the water side and even though we assume the same thickness of metal in all cases, the average temperature of the boiler metal increases as the pressure under which steam is generated increases. It is also true that with similar structures the metal thickness would increase with pressure, so that at a given rate of heat transfer its average temperature would also increase slightly because of the slightly greater temperature drop through the metal. It is also obvious that an increasing rate of heat transfer through the metal must correspond to an increasing temperature drop through that metal and thus to a higher average metal temperature.

In stationary practice and with clean water no limit to increase of pressure has yet been set by such phenomena. However, two things of interest have been uncovered. An almost unbelievably small amount of scale on the water side in 1200- to 1400-lb. pressure boilers is fatal to those surfaces subjected to high rates of heat transfer. And it is possible to show by calculation that, with heat-transfer rates which may be regarded as possible of achievement, the metal of exposed tubes in a 1400-lb. pressure boiler may reach temperatures at which the existing stresses will cause fairly rapid creep.

If one may judge from such meager evidence, it would seem that even if the locomotive boiler were modified structurally so as to

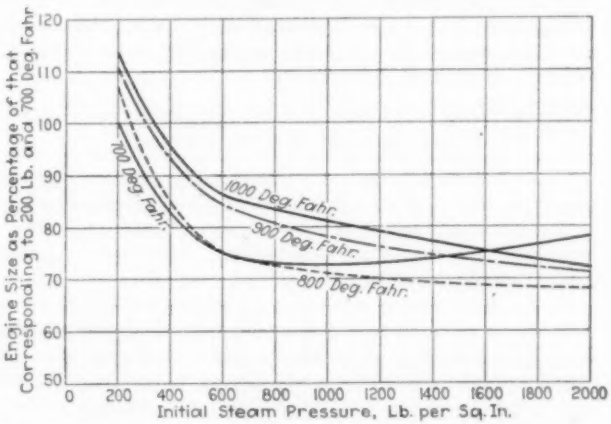


Fig. 8 Effect of Initial Steam Conditions on Physical Size of Engine. Small Turbine Plant. 5 Lb. per Sq. In. Back Pressure

adapt it to use with pressures of this order of magnitude, the feedwater conditions now characteristic of locomotive practice would make operation at such pressures impossible. In fact, I greatly doubt whether operation at a pressure as low as 400 lb. could be conducted commercially without great improvement over present feedwater practice as it exists throughout the country.

Feedwater Problem One of the Most Important

Looking at this field from the outside, I am impressed with the feedwater problem as one of the important ones that must be solved before any great advance of pressure can be contemplated safely. The situation of the railroads in this respect appears to me to be similar to that of the stationary plant of the better sort only a comparatively short time ago. It is only seventeen years since the first equipment for supplying distilled make-up in condensing stationary plants was installed, and even now we are only beginning to understand the treatments required in cases in which we cannot return an adequate supply of condensate. I confess that I do not know just how the problem should be

handled in railroad practice, but I am convinced that some better solution than that now in hand must be found before great increases in steam pressure can be safely contemplated for general use. It may be possible that the savings of various sorts that may be made through the use of higher pressures will be found sufficient to justify large, well-distributed feed-water-treatment plants, with transportation of treated water to various intermediate supply points. Or it may be that sufficiently skilful chemists can develop more perfect and simplified treatments which can be applied on the individual locomotive with such talent as is available in its operating crew. Or it may be that condensing operation will be found feasible, even though condensation be conducted at or near atmospheric pressure. I leave such considerations to those sufficiently skilled in the economics of railroading. But I do feel that the crux of the problem lies right in this factor, and that solution calls for radical thinking, for a deliberate reorientation and a new attack upon the problem.

I am also convinced in my own mind, possibly because of my ignorance with respect to the details of the problem, that the present type of locomotive boiler must pass out if much higher pressures are to be used with the maximum of economic results. Much as I admire the peculiar fitness of the present type, I cannot but feel that it represents one of those things which, surviving through its peculiar fitness, has served to limit the possibilities of improvement of major character. We have been through this thing in the stationary field and in the marine field, and it is possibly only natural to assume that we may expect a parallel development in the railway field.

Possible Devices of Locomotive Development Utilizing High Pressures and Temperatures

I have even been so bold on occasion as to endeavor to picture just what sort of boiler I would design for a high-pressure locomotive if that problem were put up to me. That it must have a water-cooled firebox is almost self-evident. That the water-cooled surfaces should take the form of tubes for high pressure instead of plates is almost equally obvious. I suspect also that the conditions of use are such that a large reservoir of steaming ability must be available in some form. Beyond these rather rudimentary specifications one would appear to have a very clear field, provided always that the problem of a satisfactory feed-water supply can be solved.

Such thought as I have given to the matter always brings me back to substantially the same picture, which I give you for what it may be worth. I conceive first of a rather large reservoir which shall be adapted to hold a volume of water substantially at boiler temperature and which shall serve as a source of steam supply to meet sudden short-time demands. Associated with this reservoir is a system of water tubes serving as a water-tube boiler. These form the firebox and, besides, give such added surface as is required to reduce the products of combustion to an acceptable temperature. Circulation through these tubes is produced by a pump which draws from the hot-water reservoir, and the tubular surface is so arranged as to discharge to that reservoir. The water tubes simply serve as a collection of heating paths starting at the pump discharge and ending at the pump suction, i.e., the reservoir from which the pump draws. Steam made is tapped off this heating system as required. I imagine that the pump speed will be regulated with respect to steam demand so that it will always circulate a large excess of water.

This may appear to you to represent very radical thinking. In one sense it is. In another, it represents a fairly logical mental extension of the path that we have followed in stationary practice. Whether it has any merit other than that of provoking comment and thus the exercise of the imagination, I know not. I do know that the imaginable solutions of the problem are so numerous that it is almost a foregone conclusion that our present one is not in all respects the best one, particularly when one considers its age and the air of assured respectability that age has conferred upon it.

One familiar with locomotive design will undoubtedly view with alarm the steam temperatures that have been suggested as desirable with higher pressures. Even a temperature of 800 to 850 deg. fahr. is not a pleasant thought in connection with locomotive engines of present design. But, once more, assuming that we retain the reciprocating engine, is the present design a necessary result? I think not.

It is almost certain that some type of poppet-valve mechanism will have to be substituted for the present types in which metal slides on metal. But I cannot see that this necessarily offers insurmountable difficulties. Cylinder lubrication, as we now understand it, will also have to be abandoned. It is at least possible to conceive of a design of piston reciprocating in a cylinder which does away with actual metallic contact between these parts and, thus, with the necessity for cylinder lubrication of any sort. Guiding and support of the piston would then have to be taken care of externally and two packings would be required. Incidentally, packing against steam at high pressure and at a temperature of 800 deg. fahr. is no mean problem but even here promising solutions are now imaginable.

If we cut loose from present designs and adopt the condensing turbine solution, many of these problems disappear, but others of equal or greater magnitude make their appearance. However, they do not seem to me in my ignorance to be more difficult than many that have been solved successfully in other fields in recent years by the simple method of breaking completely from the conventional and considering all possibilities without too great reference to past convictions.

It seems necessary to call attention to one other feature of high-pressure plant that has not been touched on. The values given in Tables 1, 2, and 3 and illustrated in several figures were calculated on the basis of a constant boiler-plant efficiency. This involved an assumption which is important in the present consideration. This assumption was that the tendency of the temperature of the flue gases discharged from the boiler to rise with increase of steam pressure, due to the increased saturation temperature, was balanced by the proper addition of heat-absorbing surface of some form. A similar problem will develop in locomotive practice if very high pressures are resorted to. It may be that the economics of the situation will prove to be such that a net gain may result from the use of higher steam pressure in spite of a greater loss to the stack. On the other hand, it may prove necessary to install auxiliary heat-absorbing equipment, such as economizers or air preheaters. The facts can be determined only by a most detailed analysis and possibly by later experiment.

In closing, I should like to repeat in slightly different form what I said in starting. I am merely commenting on your field as a rank outsider. As such an outsider I have the disadvantage of lack of familiarity with details. But I have a corresponding advantage; namely, that the knowledge of details does not prevent me from wandering mentally over many possibilities which one skilled in the field would be apt to dismiss peremptorily because of preconceived ideas.

To me your locomotive of the present day appears as the product of a marvelous development which has been carried to, or close to, its logical end. To me it appears as though the developments in other fields during the past three decades and the changes of mental attitude that have occurred in a still shorter period indicate the probability that your field is about ready to

substitute, in the near future, revolutionary changes for the evolutionary ones that have characterized it in the past. And, if this be the case, it is probable that high steam pressures and accompanying high steam temperatures, with all that they appear to portend in the way of greatly modified forms, will come in for real consideration and ultimate adoption. Such development will call for the exercise of the best that is in you, but I do not doubt but that you who have brought the locomotive to its present high state of specialized perfection will prove equal to the task if you will only attack it with a conscious rejection of all preconceived ideas; if you will test each possibility with open minds and not in the light of some generalization based upon findings, or supposed findings, of a bygone generation. I am certain that if you do attack your problem in this way you will find much valuable information in the field in which I am more at home, and I am also certain that you will find the engineers in this field more than willing to give freely of their accumulated experience for such use as you may be able to make of it.

Discussion

JAMES M. TAGGERT.[2] The author brings out several features that are essential for real progress in the application of high steam-pressure drive to locomotives.

In the first place, it is necessary to entirely change the general design from present standard practice. The present arrangement is dominated by the type of boiler used, and this type of boiler is obviously unsuited to high pressures. In the second and third places, respectively, purity of feedwater, required for high pressures, and condensation of the exhaust, requisite for efficient utilization of the steam, coordinate. Present central-station practice indicates that only by condensation can a pure feedwater supply be assured at a reasonable cost. Thus the solution of the condenser problem apparently depends on the solution of the feedwater problem.

The problem of combustion is not touched on in the paper. It is, however, intimately concerned with the other features involved in considering high-pressure steam drive for locomotives. Thus at present one of the largest losses is due to the high temperature of stack gases. With high pressures the temperature of the gases leaving the boiler would evidently be higher except as the high pressures would reduce the amount of fuel. Economizers and air preheaters would be needed to reduce this loss. On account of the increase in temperature difference in this equipment, the steam-generating efficiency could be increased without much, if any, space increase, provided a suitable design were selected.

A further large loss in present locomotives is due to incomplete combustion, especially at high loads. There is therefore required a method of fuel burning that will provide for complete combustion at higher combustion intensities within the furnace. Fortunately, pulverized-coal burning supplies this need. Recent progress indicates that with suitable fineness of pulverization, preheated air, a slag screen, and a properly designed furnace, sufficient combustion intensities can be attained for locomotive practice, provided an efficient high-pressure steam drive is used.

In connection with combustion, the question of storage of heat and combustion control is associated. Thus the author visions for the future high-pressure locomotive a rather large reservoir of water at boiler temperature. Is he not in this respect allowing himself to be influenced by present locomotive construction? With pulverized-coal feed and automatically controlled combustion, the writer is inclined to think that a properly designed flash boiler can be used. It should be considered that, except for operative control, locomotive loading depends on speed, and momentary changes in speed are not of vital importance.

All large variations in load are operatively determined. Thus combustion can be pre-regulated. This feature, combined with the ready response of a flash boiler to combustion changes, should eliminate the need of storage where pulverized or liquid fuels are used. With stokers some storage would evidently be needed, but the amount required would be less than for central stations where loading must be sustained and where combustion control is subsequent to load changes.

In considering efficiencies of steam utilization, the form of drive and arrangement are essential factors. Over the high-pressure range direct drive with steam cylinders properly designed should give a higher ratio of tractive horsepower to Rankine effect than any turbo-generator referred to electrical output. Over the lower pressure range with condensing effect, turbines are essential for good efficiencies.

The writer has taken up these points in a paper presented at the November 15, 1927, meeting of this section, and in the discussion before this section at the annual meeting last year, as well as in articles published in the September and October, 1927, issues of *Railway Mechanical Engineer*.

K. A. MAYR.[3] There are few men that have as much experience with high-temperature and high-pressure steam as Mr. Hirschfeld, and though his experience and activities may be mainly on the stationary power-plant side, the writer believes that we are to be congratulated because he gave his ideas on the application of high-pressure and high-temperature steam to locomotives. Since the locomotive engineer has so many more limitations and has to answer requirements so radically different from those with which the stationary power-plant engineer is concerned, we can understand that each step deviating from the customary design meets considerably more obstacles than if the same step is made in a stationary plant. We can understand that the locomotive designer prefers to leave the pioneering and experimenting to the stationary plant engineer, although he does not quite live up to the tradition of the early locomotive pioneer when following such a policy.

The author left the possibility of steam reheating, when using higher steam pressure, entirely out of his report. Because of the very heavy load variations on a locomotive power plant, it will be difficult to carry the initial steam temperature so high as we have it, or certainly shall soon have it, in the stationary plant. On the other hand, the much smaller and much more compact locomotive power plant lends itself quite easily to the use of steam reheaters. If reheating is introduced, we have not only dry steam in the low pressure stages of the plant, also, if we use only moderate initial steam temperature, but we are able to bend all the curves shown on the author's diagrams much more in favor of the higher initial steam pressures, and we would have a much more increasing economy for steam pressures above 1000 lb., and could continue a material improvement even up to pressures as high as 2800 lb.

The writer wishes to refer to the figures given in his paper on the ultimate steam pressures and temperatures, which was published in *Power* on April 1, 1930. These figures would favor the higher pressures still more if it would have been assumed that the high-pressure stages of the plant would be performed in a piston engine and only the low-pressure steam would work in turbines.

High steam pressures, particularly in plants of comparatively small output, such as locomotives, can be used more economically in a piston engine than in a turbine, the piston engine giving at the same time a better means to take care of the high starting torque

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[3] Chief Engineer, Siemens-Schuckertwerke A. G., New York, N. Y. Assoc-Mem. A.S.M.E.

demanded on a locomotive. The economy of the piston engine is not so sensitive to pressure variations, and a forced or speed-flow boiler can be used with small storage capacity, but built for sufficient high pressure, so that a high torque can be obtained from small cylinders. Such a boiler responds immediately to an increase in draft, and if artificial draft is provided, heavy loads can be started or accelerated with great economy. One could think of condensing the exhaust from the piston engine of, say, 200 lb. in an evaporator, as it is done with the exhaust steam of the high-pressure engines at the Deepwater Station. The feedwater question for the high-pressure boiler would thus solve itself automatically, and at the same time the water contents of the evaporator would mean a considerable steam storage capacity, so needed in locomotive service. The steam generated in the evaporator could be superheated and used in a turbine, which inherently lends itself more effectively to low-pressure steam. Feedwater heating stages could be arranged in such a system, and a condenser, which is a very difficult problem on a locomotive, could be dispensed with.

The author has already mentioned something of the decreasing dimensions of engines for steam of higher pressures. Considering the smaller amounts of steam per horsepower, the boiler heating surfaces become smaller, or if customary dimensions per horsepower are retained, become much more efficient. The same applies to the combustion chamber, and reflects itself on the space requirements for water and fuel.

The present-day locomotive already uses the allowable space to the limit, although much more power-fuel units are desired. Higher pressures would mean that 25 to 30 per cent more power could be made on the same space.

There is one point which is of great importance in these days of smoke-abatement campaigns. One need not be a combustion expert to find out when sitting on the observation platform of a modern railroad train that the combustion chamber of the present-type locomotive is too small and burns, at least on the upgrades, only half of the coal which is shoveled in. Now, if we need 30 per cent less steam to generate the required power, we need 30 per cent less coal, and as we need 30 per cent less steam, we can make it on a smaller boiler; and if we care to retain the same overall dimensions as we have them on the present locomotive, we can use not only the same size combustion chamber, but could even make it a little bigger, and the writer wonders whether that chamber would not burn 30 per cent less coal with much less smoke and certainly much more efficiently.

H. B. Oatley.[4] The Railroad Division in particular, and the railroad engineering fraternity in general, are to be congratulated on having this paper. Coming from one who has made such a thorough study and who has reached such sound conclusions, it deserves, and without doubt will have, careful consideration given to the suggestions contained therein.

It is refreshing to have this question of higher steam pressures and higher steam temperatures, as applied to the locomotive, discussed in the broad and dispassionate manner in which the author has treated it. We have in the past frequently had this question presented as a completely solved one, and have had laid down in front of us new locomotives with all of the appurtenances that are found in the up-to-date industrial plant; and while unquestionably the design on paper would show thermal advantages that commanded attention, the practical difficulties of space and weight limitations very often appeared to have been entirely overlooked. The fact that the locomotive designer cannot build a multistoried structure, nor does he have a city block on which to erect his boiler, is many times not fully appreciated by the industrial engineer who offers remedies for locomotive ills. The writer repeats, therefore, that the author of the paper has recognized these limitations, and because of that recognition, his paper has greater value than any similar presentation before the Railroad Division.

The author also has appreciation of the fact that regular attendance of a trained personnel, as found in the industrial field, becomes, with the locomotive, a case of handling and maintenance by dozens of different groups in as many different roundhouses and shops. He appreciates also the severity of operating conditions as imposed by weather, by vibration, by the use of all kinds of water, and also by the rapid and wide variation in output demand to which the locomotive must respond.

The author has pointed out the thermal advantages of increasing the steam pressure and the steam temperature, and has also indicated that there are limits beyond which thermal gain should not be expected. This is a fact that must be kept in mind in considering the further development of the locomotive and its parts.

There does not seem much doubt that the conventional form of locomotive boiler will give way to a structure in which the use of flat surfaces subjected to the higher steam pressures will be eliminated. It is true that stay-bolted fireboxes are being used for pressures up to 300 lb. per sq. in. and that flat-stayed surfaces have in a few instances been retained for pressures somewhat above this figure. In general, however, staybolts, radial stays, and diagonal bracing have disappeared when steam pressures have exceeded 300 lb., and in their place there is found the water-tube firebox with relatively small diameter steam and water drums. The indications are that this is the direction in which locomotive boilers will be developed. In marine and industrial practice, staying has almost entirely disappeared for pressures above 250 lb. per sq. in.

The point was made that with increasing steam pressures, the steam-carrying parts, as well as the prime mover, become smaller in bulk and less in weight. In the locomotive field particularly, the matter of weight is constantly before the designer, and from this angle alone the use of higher steam pressures has a decided appeal. Where reciprocating engines are used as in the locomotive, the decrease in weight of reciprocating and rotating parts is a particularly attractive feature. Should the turbine replace the reciprocating engine for locomotives, the decrease in turbine size would appear to be particularly advantageous as it would equate in some measure for the added weight of the transmission which appears to be a necessary unit of the turbine-driven locomotive.

The use of highly superheated steam has been part of the locomotive design since early in this century, and it may be added that the use of a high degree of superheat on the locomotive antedated its use in industrial practice. Steam temperatures of 650 deg. and upward have been considered as standard for the past 15 years.

The increase in steam temperature does, as the author points out, offer advantages of no small amount. The designer of boiler and superheater, and particularly the latter, is confronted with the lack of materials available for use at prices which are not prohibitive. He is in reality sitting on the doorstep of the metallurgical field, waiting for the handout of a steel which will have noticeably better physical properties and which may be worked through the same shop manufacturing operations as the carbon steels now used. It must be available at a much lower price than the heat-resisting alloy steels now on the market, many of which, while superior in physical characteristics, are not available in the forms required. As an illustration of the point, there might be mentioned the use of seamless alloy-steel boiler tubes which are available and have been used to some extent. While

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they may meet the requirements of the water-tube boiler where tube safe-ending is rarely if ever resorted to, it would at the present time be a very expensive luxury for locomotive conditions, both on account of the increased initial cost and the fact that the safe-ending of such tubes is uncertain, if not impracticable. For the superheater construction and for steam pressures thus far used in locomotive service, carbon steel to the standard specifications and for steam temperatures up to 800 deg. fahr. has served remarkably well. As we step up another 100 deg. or 200 deg. in steam temperatures, it seems reasonable to believe, as the author has pointed out, that we shall require steels having higher physical properties at elevated temperatures as well as being more oxidation resistant at the higher temperatures to which they will be subjected.

The whole tone of the paper strikes a responsive cord. To quite an extent some of the suggestions he has made have already taken form and substance. The elimination of stayed surfaces, which has already been mentioned, is not a recent development in locomotive boilers, either here or abroad. The forced circulation of water through the firebox tubes has been worked out and includes the use of a scale-free heat-absorbing medium. Forced circulation of steam through a tubular firebox structure has already been used. The multi-pressure locomotives, built and building, represent a step, possibly several steps, toward the goal which has been set by the author. In these locomotives a steam pressure of 850 lb. per sq. in. and a steam temperature of 750 deg. fahr. has been provided. This high-pressure steam is indirectly generated by steam at 1300 lb. per sq. in. generated from distilled water, circulating through water tubes forming firebox and combustion chamber. The use of this heat-transfer medium thus avoids the hazard of scale on the surfaces subjected to the high-pressure and high temperature, and, at least in part, meets one of the suggestions which the author has made.

The matter of natural versus forced circulation is admittedly a topic for thought and discussion. Forced circulation has advantages as well as disadvantages. It must be admitted that if a natural circulation which is stable and which is of sufficient intensity to protect the heat-transfer surfaces can be assured, it is preferable to a forced circulation which requires absolutely continuous operation of the circulating unit. Whether or not it is necessary to rely upon a mechanical device for such a circulation in locomotive practice, appears to be undetermined. There is no difficulty in providing it in the multi-pressure system, although thus far natural circulation has been shown to be adequate.

Alloy Steels in the Railroad Field

By CHARLES McKNIGHT,[1] NEW YORK, N. Y.

There is increased interest in the use of alloy steels by railroads. They are used purely as a matter of economics. Better work must be done at the same cost or the same work at less cost. The use of alloy miscellaneous castings materially cuts down weight with the same strength and same cost as carbon-steel castings. There are three ranges of steels: carbon steels are used for the vast majority of railroad purposes, with alloy steels for special applications, and semi-alloy steels, which are slightly more expensive than carbon steels and with slightly better properties, as a compromise. Some of their uses include boiler materials, forgings, and castings. Corrosion-resisting materials, nitriding, and miscellaneous metals are discussed and the economics of operation are given.

INTEREST among railroad technical men in the use of structural alloy steels is a very live one at the present time. This is undoubtedly due to the present necessity for lightness, strength, and increased reliability, and as the development of motive power progresses the use of these alloys will become larger and larger. As a matter of fact, the railroad field is showing a larger growth in the use of such alloys than any other one.

Steel is the most used and most useful structural material because of its cheapness and its adaptability. It is the strongest commercial material, the maximum obtainable ultimate strength being over 300,000 lb. per sq. in., yet sometimes it is used where weakness is desired, as for shear pins in machinery. It is capable of being rendered intensely hard, yet it must be very soft for such purposes as stampings and wire. With strength, toughness is usually demanded of it, yet certain so-called "screw-stock" steels are intentionally made very brittle.

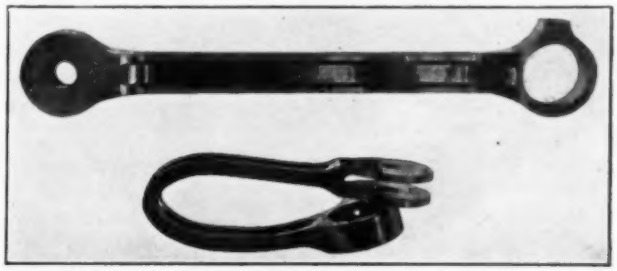
With so many contrasting qualities, it is easy to infer that steel is not simple by nature. In fact, it is a very complex material, so complex that it is difficult even to define "steel" in a satisfactory manner. Essentially it is elemental iron with varying amounts of other elements, such as manganese, silicon, phosphorus, sulphur, and carbon. Carbon is the Damon to iron's Pythias. It is very difficult to produce iron free from carbon, and it is the influence of carbon that so radically changes the characteristics of steel. A piece of soft wire, a machine bolt, a razor blade, a locomotive cylinder are all essentially the same except for the carbon content.

It is the carbon in steel which renders it so susceptible to heat-treatment; cooled slowly it becomes soft, and cooled quickly, as by plunging in water, it is capable of becoming almost glass-hard.

The history of steel is the history of man learning to produce irons with varying proportions of carbon, and learning to control and use them after they were produced. About the middle of the last century it was possible to produce commercial steel with any desired carbon from the few hundredths of a per cent that are in mild sheets up to the range where steel merges into the shadow of cast iron. At this time the empirical knowledge of the heat-treatment of steel was well abreast of the necessities of the day, although little was known of the actual role carbon played. However, industry was beginning to demand more of steel than the metal of the day could give, and these demands became more pressing as time went on. Eventually the answer came in the form of alloy steels, which opened up a new field in metallurgy and broadened tremendously the scope of engineering.

The two first alloy steels to be developed were the 14 per cent manganese steel and silicon transformer steel, but owing to their restricted uses they were not available for structural purposes. The first structural alloy steel was nickel steel. The origin of this steel lies back beyond history because all meteors are essentially nickel steel, but the first recorded use was in the Middle Ages when some of the famous Damascus swords are known to have contained nickel. In 1885 the commercial manufacture of nickel steel was begun in France, and in 1889 Riley read his paper on the subject before the Iron and Steel Institute.

This began the real growth. Creusot in France made some 3.5 per cent nickel-steel armor plate which demonstrated its superiority so conclusively that in 1890 the United States Navy



Low-Carbon Alloy-Steel Side Rod Bent Cold to Show Ductility

adopted it for armor after a conclusive and competitive test. Authorities state that the adoption of nickel steel for armor plate was as revolutionary as the construction some twenty years later of the "Dreadnaught."

By 1896 alloy steels were being used quite widely in naval vessels, for guns, armor plate, and projectiles, in heavy machinery, to a limited extent in the railroads, and quite largely for bicycles. The development of the automobile helped the growth, and from 1900 on till the present the production curve mounted steadily.

Some confusion has occurred because steels are being sold today under names indicating that they are alloy steels when, as a matter of fact, the content of "alloying element" is very slightly above that normal to all steels. An example of this is the so-called "silicon steel" which is used for ship plate and structural shapes. The silicon is actually only a few hundredths of one per cent higher than usual and the term is a misnomer. Such steel could better be called "killed steel" than "silicon steel." On the other hand, the two elements common to all steels, manganese and silicon, have valuable alloying properties, and recently these properties have been taken advantage of to produce a cheap and satisfactory steel.

An alloy steel may be defined in a general way as a steel containing an appreciable percentage of one or more elements (other than iron and carbon) conferring special virtues on the metal. This definition, however, does not tell the whole story. To be worthy of the name, alloy steel must necessarily be of a better quality and made better than a similar straight-carbon

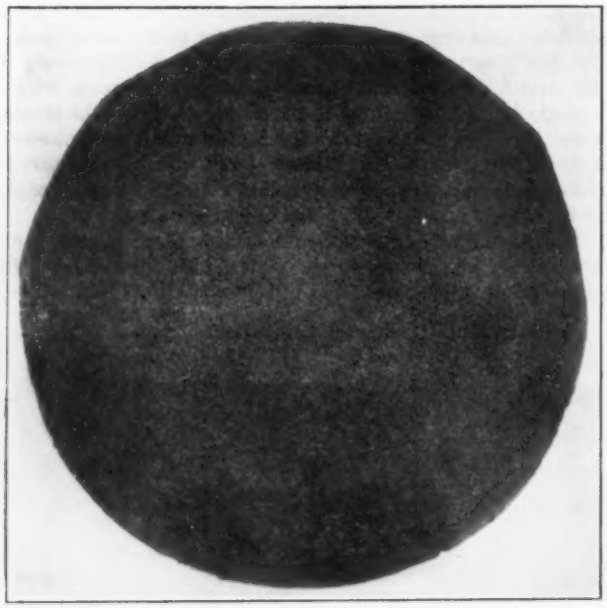
[1] The International Nickel Co., Inc.

Contributed by the Railroad Division and presented at the Annual Meeting, New York, N. Y., Dec. 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

steel. Otherwise a large part of the advantage gained by the alloy addition is lost. It is probable that, were it possible to remove the alloy from steel after manufacture, the alloy steel would still be superior to ordinary steel, simply on account of the additional precautions taken.

This quality is one reason for the additional cost of alloy steels. If the price per pound of alloy steel is analyzed, it will be found that the alloy addition alone is not sufficient to account for the excess cost. For example, 3.5 per cent nickel steel is currently quoted in bar form at 4.15 cents per pound, while



ETCHED SECTION OF FORGING FOR MAIN DRIVING AXLE SHOWING AVERAGE STRUCTURE

carbon-steel bars are a little under 2 cents per pound. The nickel addition alone, even at 35 cents per pound for nickel, accounts for not quite 1.25 cents. Therefore, almost one cent, or little less than the cost of the alloy, goes for the "quality factor." Although this may seem out of all proportion, it is not unfair for the steel manufacturers to make such a charge, providing the steel is really of good quality.

The designing engineer finds at his hand three types of steel.

Carbon Steels. These steels are used for the vast majority of purposes for very good and economical reasons. There is a tendency, in the view of recent metallurgical developments, rather to belittle carbon steel, but it should be remembered that conscientiously made carbon steel will in most places give more per dollar than any other structural material. The field of locomotion by land, water, and air furnishes an outstanding exception to this generalization.

Alloy Steels. Alloy steels are essentially special steels for special purposes. The growth in their use has been and will be rapid, but it is a mistake to use an alloy steel where its use is not justified.

Semi-Alloy Steels. This term is really a misnomer as there should be a sharp distinction between alloy steels and carbon steels. At the present time, however, there are steels on the market which have had relatively small extra additions of metalloids ordinarily used in making steel. They are slightly more expensive than carbon steels with slightly better properties. They are a compromise between the two other grades, and it remains to be seen if they can justify themselves economically.

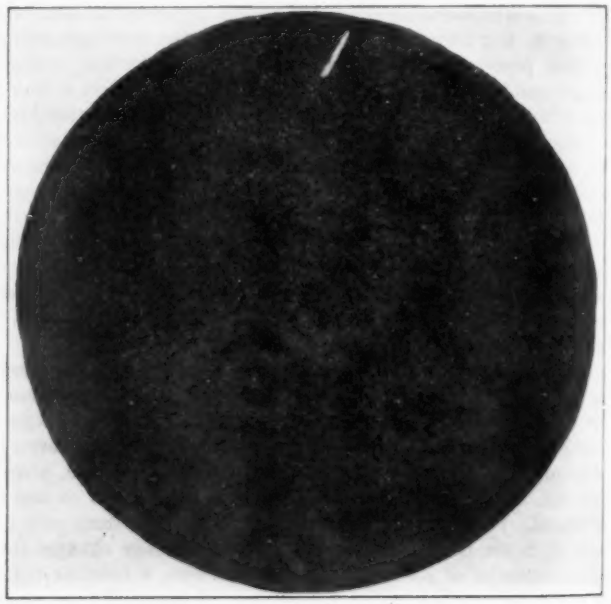
ALLOYING ELEMENTS AND CHARACTERISTICS

The most common alloys used in the manufacture of structural steels are nickel, chromium, vanadium, molybdenum, manganese, and silicon.

Nickel. It is used in ranges from 0.50 to 5.0 per cent for structural steels, but its useful range is from 0 to 100 per cent. It alloys with iron in all proportions, but does not form carbides or oxidize in a furnace. It responds to heat treatment and is added for toughness, strength, and hardness.

Chromium is used in ranges from 0.25 to 2.00 per cent for structural steels, and in higher ranges for corrosion- and heat-resisting purposes. It acts on steel through carbide formation, oxidizes in steel-making processes, and responds to heat treatment. It is added for hardness and strength.

Vanadium is used in ranges of not over 0.25 per cent in structural steels, though up to 2.0 per cent in high-speed tools. It acts through carbide formation, oxidizes very easily, and is, therefore, a powerful scavenger. It responds to heat treatment and tends to refine grain. It usually is used in combination with other alloys, and is added for strength and toughness.



ETCHED SECTION OF FORGING FOR MAIN DRIVING AXLE SHOWING VERY POOR STRUCTURE

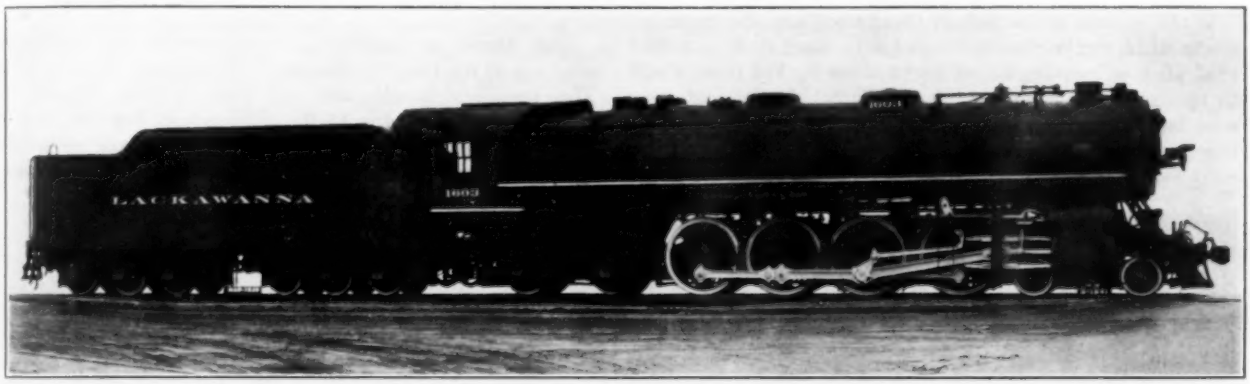
Molybdenum is used in ranges up to 0.50 per cent in structural steel. It acts principally through carbide formation, does not oxidize, responds to heat treatment, throws scale in forging operations, is rarely used alone, and is added for strength and hardness.

Manganese is present in all steels below 1.0 per cent. It is used in ranges from 1.0 to 2.0 per cent in structural steels, acts through carbides, but is also dissolved in iron constituent, oxidizes readily and is a very good deoxidizer, and responds to heat treatment, but gives somewhat erratic results and requires great care. With some other alloy acting as a restrainer and toughener, it is much less erratic and is added for strength.

Silicon is present in all steels up to 0.60 per cent, as it is added for a deoxidizer. It is not used in strict structural service except for springs, where it is used in ranges from 1.00 to 2.00 per cent and is most used in electrical transformers in ranges of from 3.00 to 5.00 per cent. It oxidizes very readily. It is interesting to

note that the strongest steel (not cold-worked) of record is a nickel-silicon.

Of these alloys, nickel is the most used either alone or in combination with other elements such as chromium and molybdenum. The reason for this is that in addition to the benefits derived through the effect of the alloy itself on the steel, nickel is the only alloy which goes entirely into the iron constituent of the steel, thus rendering it independent of the carbon. It is one of the two alloying elements which do not oxidize in the steel furnace, thus making the process of manufacture simpler and more certain, as well as making it possible to recover all nickel from scrap, and it has a wider useful range (0 to 100 per cent) than any other alloy.



Locomotive Using Alloy-Steel Forgings

Forgings of Alloy Steel

The locomotive designer in recent years has adopted alloy steel for forgings more generally because of the larger power units, and because the size of forgings cannot be increased indefinitely. Strictly speaking, it is not a new development. In the early days of alloy steel the railroads were among the first users, but alloy steels got quite an unsavory reputation with them. The reason for this was that it was not then appreciated that mass makes a great difference in the properties of forgings, and that the heat treatment must conform to the size of the piece. It is manifestly ridiculous to compare the $1^1/_4$-in. rear-axle shaft of an automobile with a 10-in. or 12-in. locomotive driving axle, and yet, in the early days, the same steel and the same heat treatment were used for both with disastrous results in the case of the driving axle.

Fifteen or so years ago, after a temporary lapse, alloy steels again began to be used with intelligently written chemical specifications, and intelligently conceived and controlled heat-treatments. While quite a number of alloy-steel forgings are still heat treated by quenching in some liquid medium such as oil or water, it is generally conceded that such drastic treatment, while producing higher strength, is not conducive to the greatest reliability. Strength is, therefore, sacrificed to a slight extent, the cooling medium is air instead of a liquid, and the large forgings of today are much freer from strains and cracks.

The heat treatment in general use today for large railroad forgings is specified by the term "normalize and draw" or "normalize and temper." In this process the metal after forging but before machining is slowly heated to a predetermined temperature, and is held at that temperature one hour or more for each inch of cross-section. The predetermined temperature is one higher than the so-called "critical point" of the metal, at which the various constituents of the steel merge into an amorphous solid solution. This critical point varies with the carbon and alloy content of the steel. The higher the carbon, the lower the critical point. The alloy having the most marked effect is nickel, which has a tendency to lower it. Sixteen hundred deg. fahr. is, in the absence of accurate data, taken generally as a safe temperature for normalizing. Higher temperatures than this induce excess grain size, and lower ones are not safely above the critical point.

After the steel has remained at this temperature the required time, it is removed from the furnace and is allowed to cool in still air, free from draughts and not exposed to rain, snow, or other chilling agency. When it has cooled so it is no longer red, it is replaced in the furnace and heated to the "drawing" or "tempering" temperature. This is in order to free the metal from stresses set up by cooling, and to put it in the best condition for service from a metallurgical standpoint. The drawing temperature must, of course, be lower than the critical point. It is usually about 1100 to 1200 deg. fahr. and the forgings are again kept at that temperature for one hour or more for each inch of cross-section, after which they are cooled either in the air or furnace. It does not matter greatly which cooling method is used, but probably the air cooling is preferable.

Good heat treatment of alloy-steel forgings is an essential, but again quality is a great factor. No alloy ever made bad steel good. It is necessary, as a metallurgist has aptly said, to begin the manufacture of alloy steel with its pre-natal care, and, as a railroad man even more aptly said, to choose your steel-maker as you would your physician. Quality brings in so many details, such as method of manufacture, rolling vs. pressing, etch-tests, etc., that they can hardly be hinted at, much less discussed, in a paper of this length.[2]

The majority of alloy-steel forgings now made conform to one of the following types:

1 Carbon-vanadium steel, normalized and tempered.
2 Nickel steel, normalized and tempered.
3 Chrome-vanadium steel, quenched and tempered.
4 Nickel-chromium steel, quenched and tempered.

The first two air-treated types probably account for more than 75 per cent of all alloy-steel locomotive forgings, as the latter two are not widely used.

As representative of what may be obtained from an alloy-steel forging of large size, normalized and tempered, carbon-vanadium steel analyzing:

Carbon	0.40–0.50 per cent
Manganese	0.75–0.90 per cent
Vanadium	not less than 0.18 per cent

[2] For an extended discussion of these factors, the author recommends the paper on "Locomotive Forgings" by Lawford H. Fry. Transactions of the American Society for Steel Treating, to be published presently.

will give on the average tensile values of:

Ultimate tensile strength	90–100,000
Yield point	60– 70,000
Elongation in 2 in.	22–28 per cent
Reduction of area	40–45 per cent

For comparison, carbon steel with about the same carbon (0.45–0.50) will give:

Ultimate tensile strength	75–85,000
Yield point	40–50,000
Elongation in 2 in.	18–25 per cent
Reduction of area	35–42 per cent

In the opinion of the author, these are about the maximum results which can be obtained from a normalized steel, no matter what alloy or combination of alloys is used. Yet there is still an uncomfortably large number of failures. In the past there were failures with wrought iron, so steel was adopted; there were failures with steel, so alloy steel was adopted. Perhaps our reasoning has been wrong, and strength is not the absolute criterion of a good locomotive forging. In the past six years there has come into prominence and popularity a steel which deliberately sacrifices a little strength to obtain a lot more toughness and shock resistance. The carbon content is much lower than is usual, and nickel is the supporting alloy. Such a steel, normalized and tempered, has in large locomotive forgings given an average of:

Ultimate tensile strength	83,535
Yield point	60,371
Elongation in 2 in.	31 per cent
Reduction of area	60 per cent
Carbon	0.24 per cent
Nickel	2.58 per cent

Impact tests are illuminating. Izod impact values on this steel, made on test pieces from large forgings, run 50, 60, 70 ft-lb., and even higher. This indicates more than double the shock-resisting capacity of the usual higher-carbon alloy steel. Such a steel merits attention.

Alloys Used in Castings

A large proportion of the weight of a locomotive is made up of castings, both steel and iron. The frame alone constitutes a considerable part of the locomotive weight. Alloys are employed in these castings either to strengthen and toughen them, or by strengthening, to make possible the employment of lighter sections. Sometimes special characteristics are sought, such as wear resistance in cylinder bushings and heat resistance in iron grate bars.

It is believed that the first alloy-steel castings to be extensively used by the railroads were carbon-vanadium. This was introduced for locomotive frame castings some fifteen years ago, and excellent results have been obtained with it.

The alloys, alone or in combination, most employed in railroad work for steel castings are, vanadium with content not less than 0.18 per cent, manganese 1.00 to 2.00 per cent, and nickel 1.50 to 3.00 per cent. With a carbon content of from 0.30 to 0.40 per cent, these alloy steels give minimum physical characteristics of

Ultimate tensile strength	80,000
Yield point	45,000
Elongation in 2 in.	25 per cent
Reduction of area	45 per cent

Such figures are obtained on large castings, such as frames, after a heat treatment consisting of normalizing and tempering. This treatment is essentially the same as that detailed for forgings. However, due to the difference in the structure of castings as compared with that of rolled or forged steel, it is quite usual to employ a preliminary heat treatment known as a homogenizing treatment. This is carried out at a higher temperature (1600–2000 deg. fahr.), and the castings are air-cooled. By it the original casting structure is more completely broken up. Smaller castings will have somewhat higher properties, and for such castings it is often permissible to use the "quench-and-temper" treatment to obtain even better results, provided the section is not too intricate. In this field, too, interesting results have been obtained by departing from the conventional, and using a low-carbon alloy steel.



Alloy-Steel Side-Frame Casting Weighing 13,250 Pounds

A valuable application of alloy steels for castings was brought out by the chief mechanical engineer of one of the largest systems on this continent. He could obtain low-carbon alloy-steel castings at approximately 35 per cent increase in price over ordinary steel castings. He therefore designed some new power to use alloy-steel castings, cutting down the section on all castings to $^1/_3$ of the former size, but maintaining a minimum section of $^1/_4$ in. By these means the net cost of the castings per locomotive was the same, but the total weight of castings was $^1/_3$ the previous figure, and the strength was slightly higher. The saving in weight per locomotive was on the order of 10,000 lb., which could be applied to power-producing purposes.

In the past few years there has been a vogue for the one-piece locomotive frame. These intricate and large castings are a tribute to the skill of the steel foundrymen. Hitherto they have been made from an ordinary low-carbon steel, both for simplicity and to facilitate welding. Some few frames have recently been made with a low content of alloy and it may be predicted with confidence that future developments will include the further use of alloys in order to improve the strength and toughness of these castings.

Boilers of Nickel Steel

The present tendency toward higher boiler pressures has made the designer turn to other materials for boiler construction. Increased boiler pressure means increased boiler weight, if carbon steel is employed. In addition, in many cases the thickness of the plate now being used is about the maximum which can be handled.

Faced with this problem, in 1926 the Canadian Pacific Railroad adopted nickel steel for boilers, and succeeded in increasing the boiler pressure 25 per cent without any increase in weight. The steel employed, a 3.0 per cent nickel steel with a minimum tensile strength of 70,000 lb. per sq. in., was approximately 30 per cent stronger than carbon steel, and therefore the factor of safety in spite of the increased pressure was actually higher than before. On this first order 44 locomotives were constructed, 24 Pacific type and 20 Mikados. Today there are over 150 such boilers in service on the railroads of this country and Canada, and in no development is there greater interest among railroad operators.

While this step was apparently unprecedented, inquiry has since developed that in 1904 a locomotive was built employing nickel steel for the boiler and this is still in service. Some years earlier this plate had been used for the tubes and boilers of the *U.S.S. Chicago*, so the question of how the material would stand service was answered.

For high-pressure boilers the only two steels used in any quantity have been manganese, from 1.00 to 2.00 per cent, and nickel, 1.75 to 3.25 per cent. The vast majority of alloy-steel boilers, in fact practically all, have been made from nickel steel for two reasons. First, boiler plate is per se a low-carbon material, and nickel not being dependent for its alloying qualities on carbon confers higher properties than any other alloy. Second, while it is possible to obtain as high or higher strength with other alloys, nickel steel develops to a very high degree resistance to embrittlement and aging,[1] and has unusually satisfactory strength at boiler temperatures, a necessity often neglected.

The tensile results obtained with a 3.0 per cent nickel-steel boiler plate, together with those of carbon-steel plate for comparison, are shown in the following table:

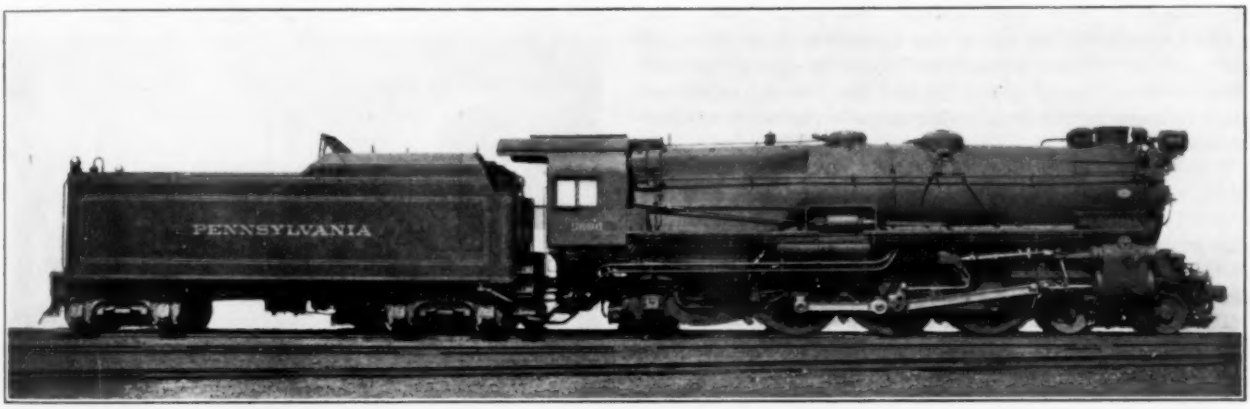
AVERAGE OF 385 TESTS ON CARBON STEEL BOILER PLATE

	Average per cent		Average
Carbon	0.193	Ult. Tens. Str.	59,200
Manganese	0.041	Yield Point	36,200
Phosphorus	0.022	Elong. in 8 in.	28.64 per cent
Sulphur	0.033	Red. of Area	(Not determined)
		Impact, Izod	(Not determined)

The mechanical engineer may ask what will happen if even higher pressures are required in the conventional fire-tube boilers. The answer is that nickel-steel boiler plate can be manufactured with a tensile strength of 100,000 lb. or more, but it is not desirable to do so at present.

Corrosion Reduction

There are two types of materials which are useful for use under corrosive conditions: (1) Corrosion-resisting materials, and (2) non-corroding materials.



Locomotive With a Nickel-Steel Boiler

Under the corrosion-resisting type of materials are found such metals as wrought iron and commercially pure iron (Armco), together with low-carbon steels bearing slight percentages of such corrosion inhibitors as copper, molybdenum, and nickel. While these materials are not offered as being rustless or corrosion-proof, they have proved in long service that under certain corrosive conditions and also exposure to the atmosphere, their life is much longer than that of ordinary steel. Economically they are attractive because, being essentially a steel, their cost is not very much greater than ordinary carbon steel for the same purpose. They are suitable for such purposes as car plates, underframes, firebox sheets, etc.

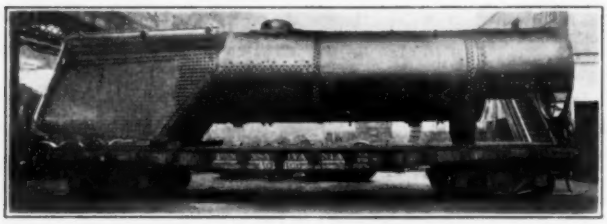
The second field is a comparatively new development. About ten years ago laboratory experiments indicated that a steel containing chromium around 20 per cent exhibited certain "stainless" properties. These steels were of fairly high carbon, i.e., about 0.30 per cent, and were first developed for cutlery and other similar purposes. In this original development it was soon found that their resistance to corrosion was not perfect, and depended to a great extent on the heat treatment which had been given the material and on the finish. The next step was to reduce the carbon as low as possible so that the alloy was really a chrome-iron rather than a chrome-steel. This material was soft and ductile, and not dependent for corrosion-resistance to the same degree on either heat treatment or finish. It has proved very acceptable. For the next step we are indebted to German metallurgists when they

[1] For further discussion of these phenomena see "Alloy Steels for Boiler Construction." Trans. American Society for Steel Treating, 1928.

AVERAGE OF 523 TESTS ON 3.0 PER CENT NICKEL-STEEL BOILER PLATE

	Average per cent	Specified per cent		Average lb. per sq. in.	Specified lb. per sq. in.
Carbon	0.163	0.20 Max.	Ult. Tens. Str.	77,880	70,000 Min.
Manganese	0.557	0.40–0.80	Yield Point	47,550	50 per cent U.T.S.
Phosphorus	0.021	0.045 Max.	Elong. in 8 in.	36.33 per cent	1,600,000 U.T.S. Min. 20 per cent
Sulphur	0.029	0.045 Max.			
Silicon	0.203	Not Spec.	Red. of Area	54.15 per cent	50 per cent
Nickel	2.960	2.75–3.25	Impact Value, Izod 63.4 ft-lb.		

added nickel to the alloy. This resulted in a material which was superior to either of the other two in resistance to corrosion, in appearance, and in workability, and it is now probably the preeminent type of non-corroding steel. It is, of course, sold under a trade name but is manufactured by several companies in this country.



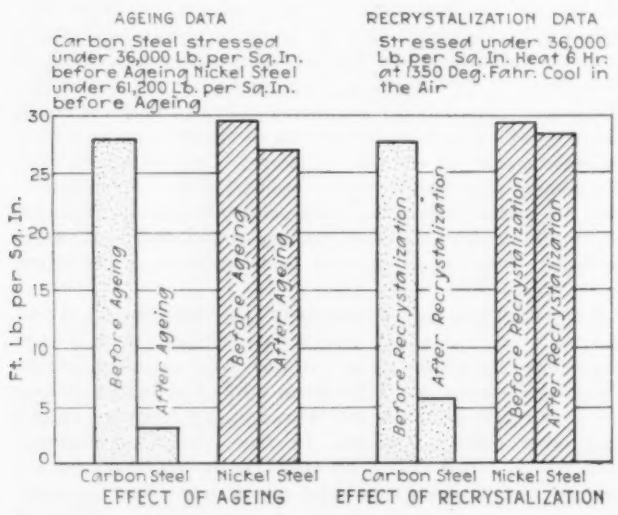
High-Pressure Nickel-Steel Boiler for Locomotive

The economics in the use of this material is that, due to its high price, say 30 cents a pound and higher, it can only be used where the conditions of service are such that the cost is justified either in longer service or in saving cost of replacement of other materials.

It has been used successfully for such purposes as condenser tubes, boiler tubes, superheater parts, etc. To date it is not known that it has been used for firebox sheets, but its use has been contemplated and it would appear that this would be an excellent application on sections where the corrosion conditions are very bad.

The physical characteristics of the chromium-nickel-iron alloy (chromium 18 per cent, nickel 8 per cent, carbon less than 0.16 per cent) are as follows:

Ultimate tensile strength	85–95,000 lb. per sq. in.
Yield point	30–40,000 lb. per sq. in.
Elongation in 2 in.	57–60 per cent
Reduction of area	70–75 per cent
Brinell hardness number	130–145



Comparative Aging and Recrystallization Tests of Alloy Steel and Carbon Steel for Boilers

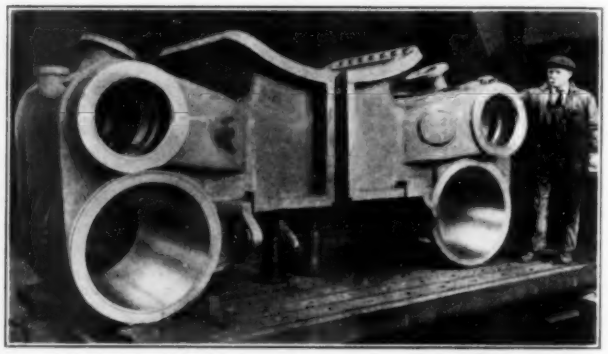
This alloy in addition has excellent characteristics which make it valuable for high temperature work and it can be continuously employed at temperatures as high as 1700 deg. fahr.

It should be noted that in order to develop the maximum resistance to staining or rusting, the surface must be carefully freed from all scale and should be polished.

Miscellaneous Uses of Alloy Steels

There are a number of miscellaneous uses for alloy steels in the railroad field. For example, engine bolts are quite frequently made from alloy steel and are used in either the case-hardened or the heat-treated condition. Nickel-steel staybolts are quite general. Rivets, especially for alloy-steel boiler plate, are often of the same material as the plate itself. Roller bearings, which seem to be coming into favor with the railroads, are, of course, entirely made from alloy steel.

In this connection the use of roller bearings will probably develop a demand for an alloy steel or iron wheel. The length of installed life of a roller bearing is today not dependent on the bearing itself, but on the wheel life, and if the wheels can be made more wear-resisting, it will not be necessary to dismantle axle units so frequently. There is no question that wheels, either steel or iron, can be improved by the addition of alloys, such as manganese, chromium, nickel, and molybdenum. There



Alloy Cast-Iron Locomotive Cylinders

are today in service many thousand wheels in which manganese is used as an alloying element, and experiments are being undertaken by some of the largest wheel manufacturers to improve their product. It is possible to make a chilled-iron wheel containing alloys which will be much stronger and more wear-resisting than the present chilled wheel, but the decision to use these wheels must come from the railroads. As one chilled-wheel manufacturer stated some time ago, their business is to trade a new wheel for one discarded by the railroad, plus 80 cents. Naturally, an alloy wheel cannot be furnished on this basis.

Chilled wheels, however, are not the only places where cast iron is being improved by alloys. In the last three years there has been a tremendous growth in the use of alloys in cast iron, and today in railroad service such castings as cylinder bushings, cylinders, packing rings, etc. are being made from an iron bearing either nickel, chromium, or molybdenum, alone or in combination. Two of the largest locomotive manufacturers are making nickel-cast-iron cylinders which compare so favorably with steel cylinders that it is doubtful whether it is worth while to use the cast-steel cylinder.

Another new development which is being watched with interest by the railroad men is that of "nitriding." While the process might still be called in the experimental state, and there is no finality as yet, there is considerable promise that this will prove to be a valuable tool in railroad work. By this method a chrome steel with 1 per cent of aluminum and with or without other elements[4] is machined to the final shape ready to be used, heat-treated, and then exposed to an atmosphere of ammonia

[4] The analysis most used in this country is chromium 0.80–1.30, aluminum 0.60–1.20, molybdenum 0.15–0.25.

gas at 1000 deg. fahr. or slightly less. After some time at this temperature and exposed to this gas the metal takes on an intensely hard surface. It is possible to procure a surface hardness of around 1000 Brinell, whereas about the hardest steel obtainable by other methods of heat-treating is in the vicinity of 600 Brinell. In addition, since the temperature used is comparatively very low, there is practically no distortion or warping of the parts. The value of such a hard material can be easily appreciated, and numerous applications to railroad work can be thought of. For example, one might mention piston rods, crosshead guides, crank pins, valve-motion work, and even axles. One manufacturer is today experimenting with main driving axles where the journal alone is nitrided, and the wheel fit and main body are blanked off so that the ammonia gas does not affect them. The value of this remains to be proved.

Nitriding has been developed to a higher degree in Europe than it has in this country, and recently an opportunity was presented of observing the process as practiced by one of the largest companies in Europe. They were nitriding such parts as automobile cylinder blocks, railroad bumpers, valve-motion pins, piston rods, crank pins, pump shafts, gears, and a large variety of other parts, and it was easy to gain the impression that this process was applicable to practically everything. A word of caution, however, would not be inadvisable at the present time as it is quite probable that enthusiasm will run away with common sense. In the author's opinion, one should be very careful in using parts which have been treated by nitriding where there is any impact, such as in gears, because the hard case on this material is extremely thin and also extremely brittle, and spalling is almost inevitable. On the other hand, where the pressures are not too heavy, and where the contact is either sliding or continuous, it would seem that nitriding steels offer a very great advantage.

Conclusions

In a very general way the use of alloy steels by the railroads has been covered. Necessarily also, the treatment has been brief. It would be possible to write a fair-sized book on the subject without exhausting it. In closing, we recommend that these remarks be considered in this light and that, in case any question whether or not to use alloy steels arises, metallurgists competent to deal with the problem be consulted.

Discussion

G. L. Norris.[5] The use of alloy steels for various purposes is of great interest and importance to the railroads, as is shown by the increasingly large tonnages they are using.

The constantly increasing size and power of the modern locomotive have developed a condition that requires the use of special or alloy steels of higher strength than the carbon steels heretofore in general use, not only to meet the higher stresses, but to keep the wheel loads within the specified limits and to lighten the reciprocating and revolving parts, thereby permitting of better counterbalancing and reducing dynamic augment. Strength is the primary requirement, coupled of course with a good degree of toughness and shock and fatigue resistance.

With reference to failures, records and investigations show that the greater number, possibly 90 per cent or more, are due to mechanical causes, such as fit, finish, and maintenance, and only a very small percentage to actual inferior quality of the material. Tool marks, sharp fillets, and lack of lubrication are the fruitful causes of many failures.

With reference to vanadium, which is the alloy element in 90 per cent or more of the alloy-steel locomotive forgings and castings in use today, the writer would like to correct the impression that the paragraph on the second page of the paper describing its characteristics might leave—that it is used as a deoxidizer or scavenger when added to steel.

Vanadium has a special place in the periodic system of the elements, as it lies between those elements used as deoxidizers and those used as fixed additions and carbide forming. While it can serve both purposes, it is not employed for deoxidizing, but is added for its alloying qualities after the deoxidation has been accomplished by cheaper and more powerful deoxidizing elements, such as silicon and aluminum. It is therefore used solely as an alloying addition in imparting fine grain size and greatly improving the strength and other properties of steel.

Vanadium in combination with carbon acts with the greatest intensity of any of the elements in improving alloys of iron—that is, in small quantities. Steels containing vanadium in appreciable amounts, sometimes even as low as 0.05 per cent, show much less dendritic segregation than do vanadium-free steels, almost complete freedom from Widmanstattian patterns after casting and before thermal or mechanical treatment, and are generally characterized by extremely fine grain size. They likewise retain this fine grain size at higher temperatures than vanadium-free steels.

Vanadium has a very strong affinity for carbon, even stronger than oxygen, and when added to steel is found combined principally with the carbide or cementite and partly with the ferrite. The ferrite containing vanadium is stronger, tougher, and harder than ordinary ferrite. The carbide is likewise greatly strengthened and hardened, shows a very much less tendency to coalesce or form into large masses, and tends to remain in the sorbitic condition. Therefore, segregation of carbides is less common in vanadium steels, and lamellar pearlite does not readily occur at ordinary rates of cooling. This tendency of vanadium to form sorbitic pearlite, even in large forgings, is a unique and valuable property.

The benefits of these various effects of vanadium on steel are immediately apparent in improved physical properties and uniformity of response to heat treatments. The tensile strength is increased and the elastic ratio raised without materially lowering the ductility. The resistance to shock or impact, reversal of stresses, or fatigue and resistance to wear or abrasion are very considerably increased. Vanadium also imparts thermal stability to steels by hindering the growth of carbide particles and by restraining the decomposition of the carbides at elevated temperatures.

With regard to quenched and tempered forgings, probably the troubles encountered with these were due largely to the lack of equipment and experience on the part of some of the manufacturers. It was to overcome this that the normalizing and annealing treatment of locomotive forgings was developed with alloy steels. By this treatment no unrelieved quenching strains are left in the forgings, and physical properties are obtained practically equal to those by a mild quench and tempering treatment.

Typical physical properties of normalized and tempered or annealed carbon vanadium forgings are:

Yield point, lb. per sq. in.	65,000
Tensile strength, lb. per sq. in.	97,000
Elongation in 2 in., per cent	24
Reduction of area, per cent	45 to 52

The minimum physical properties given by the author for alloy-steel castings are not those to which most of these castings are made today. These should be:

Yield point, lb. per sq. in.	55,000
Tensile strength, lb. per sq. in.	85,000
Elongation in 2 in., per cent	22
Reduction of area, per cent	40

[5] Vanadium Corporation of America, New York, N. Y.

Typical values of castings to this specification are:

Yield point, lb. per sq. in.	57,000
Tensile strength, lb. per sq. in.	90,000
Elongation in 2 in., per cent	24
Reduction of area, per cent	47

Recently there has been developed a nickel-vanadium cast-steel specification that gives the same tensile properties with increased ductility. The specification for this steel calls for the following minimum properties:

Yield point, lb. per sq. in.	55,000
Elongation in 2 in., per cent	25
Reduction of area, per cent	50

The average properties obtained are:

Yield point, lb. per sq. in.	59,000
Elongation in 2 in., per cent	28
Reduction of area, per cent	58

Typical composition of this steel is:

Carbon	0.20
Silicon	0.35
Nickel	1.50
Manganese	0.80
Vanadium	0.10

It will be noted that the percentage of carbon is considerably lower than given by the author for the other alloy-steel castings.

With reference to embrittlement and aging of nickel-steel plates, it is noticed that the data given are all for 5 per cent nickel steel. It would be valuable if such data could be given for the 3 per cent and lower nickel plates generally used in boilers.

There is one very important and growing application of alloy steels on the railroads that the author has overlooked; this is locomotive and car springs. There are several thousand springs of chrome-vanadium steel already in successful service.

A direct comparison between springs in which carbon steel is used and chrome-vanadium practice is perhaps as good a way as any to demonstrate the advantage gained through the use of vanadium steel for railroad springs. Under average manufacturing conditions and heat treatment, the physical properties of the two steels will be about as follows:

	Carbon	Chr. van.
Elastic limit	135,000	190,000
Ultimate strength	180,000	200,000
Elongation in 2 in., per cent	6	10
Reduction of area, per cent	15	30

In addition to these tensile properties, and of more practical importance, it has been found that the safe commercial stress range for carbon steel is somewhere between 55,000 and 60,000 lb. per sq. in., while in the case of chrome vanadium it has been found safe to increase this to 75,000 to 80,000 lb. per sq. in. Also, the fatigue and impact values, no matter how measured, are very much superior in the case of chrome-vanadium steels.

Since these engineering characteristics are the limiting factors in determining the design and performance of a spring, it is apparent that the superior values obtained in chrome-vanadium steel may be used to a practical economic advantage in spring construction. One may either safely increase the flexibility of the spring and hence obtain easier riding qualities, or increase the length of life of the spring under any given service conditions, or reduce the weight of the spring, or adopt some desired combination of these three.

C. F. Pascoe.[6] The recent developments of the so-called stainless steels and nitriding alloys are being closely watched by the Canadian Railways and will undoubtedly be tried out on material which promises good results.

It is understood that European practice still favors oil-quenched and tempered forgings for locomotive driving axles, in spite of the fact that much trouble has been experienced in the United States and Canada from such treatment, particularly on driving axles. Can the author give some information regarding the composition of steel so treated in Europe, particularly regarding the alloys used, if any.

The author mentions that the quench and temper treatments on steel castings will give considerably higher figures than those mentioned in his paper. Some time ago our foundry quenched 20 tons of low-carbon nickel-steel castings in water at 120 deg. fahr. and drew them back at 900 deg. fahr. The average of many tests on the attached coupons was as follows:

Yield point, lb. per sq. in.	62,000
Tensile strength, lb. per sq. in.	92,300
Elongation in 2 in., per cent	23
Reduction of area, per cent	59

All castings were subjected to a drop test afterward to determine if any quenching cracks had developed, but none were found. The results show that low-carbon alloy-steel castings, even if of intricate design, can be water-quenched without much fear of cracking.

The writer is interested in the author's statements regarding low-carbon alloy steels, as our foundry has cooperated in considerable development work in this respect for the Canadian Railroads. Izod-impact values on double heat-treated low-carbon nickel-steel castings, on account of being so much higher than those obtained on other grades of alloy-steel castings we have made, have considerably influenced our railroads in regarding the adoption of this grade of steel for locomotive castings, particularly main sideframes.

W. H. Winterrowd.[7] This paper is timely and contains much valuable information, and particularly interesting is the discussion, which will prove equally valuable. Regarding the discussed difficulty of a railroad keeping track of alloy-steel parts, it is felt that this difficulty can be eliminated by simple systematic methods and proper supervision.

As this paper will be read with a great deal of interest by many railroad men who have had some experience with alloy steel or who are experimenting with it, the writer thinks that it would be of value and interest if the author would explain why it is possible for different billets from separate sources or sometimes from the same source to have such different or varying characteristics even though the billets have passed widely accepted specifications and have been subjected to exactly the same methods of heat treatment.

A. W. Minuse.[8] The paper accurately sums up the alloy-steel situation in the railroad field today. Alloy forgings, which are so generally used in the automotive industry, have not been so extensively used on locomotives for several reasons. Heat-treating such large sections requires care and good equipment, and the careless application of heat to some part of a treated forging in making repairs destroys the structure given by heat treatment, and failure of the part is the inevitable result.

Air quenching, or normalizing, followed by a draw is the most favored treatment, as quenching in oil or water, especially on very large sections, does not seem to be advisable at the present time. Unfortunately this means that one must take lower

[6] Technical Engineer, Canadian Steel Foundries, Limited, Montreal, Que.

[7] Vice-President, Lima Locomotive Works, Inc., New York, N. Y. Mem. A.S.M.E.

[8] Central Alloy Steel Corporation.

physical properties than are obtainable, to insure freedom from cracks and internal stresses, a condition which does not embarrass the automotive field. Locomotive designers have not, except in rare instances, taken advantage of the higher physicals of alloy steels to reduce sections and weight, but have in most cases been satisfied to use the higher physicals on the same sections, striving for longer service life of the part. Undoubtedly with the increasing tendency toward wider application of alloy steels the railroads will in the near future begin to utilize their higher physical properties to obtain sufficient strength on lighter sections. A better understanding of these steels and better heat-treating equipment in the railroad shops will follow, and the future will see oil- and water-quenched alloy-steel forgings being extensively used.

As the author points out, higher steam pressures and their resulting higher boiler temperatures will require greater strength in boiler plate, if the boiler is to be held to the same weight. This situation has been successfully met by the use of a 3 per cent nickel steel. Under actual operating tests plates of this analysis have also proved to be of great value in firebox construction. In this connection the 18 per cent chromium irons have been used as inside firebox sheets and have proved conclusively that in spite of the high cost of this material its use is economically justified. This material is stainless, and after two years' service in this application was clean and free from scale. Its real value lies in the fact that its brittle temperature range is far higher than any temperature it can attain in service, while the higher pressure boilers raise the temperature of carbon-steel firebox plates into the brittle range of this material. Fatigue of these carbon plates is very rapid with the metal in this condition, and many failures are directly due to this cause. Several engines are at present being equipped with fireboxes and siphons made entirely of this chromium iron.

Nitralloy is being tested by many railroads. These intensely hard surface steels, with their ductile heat-treated cores, can be expected to fill a long-felt want where friction and its resulting wear have caused trouble. The case of these steels retains it hardness at temperatures exceeding 1200 deg. fahr.

The author has accurately stated that this material should not be used where impact stresses are a factor. However, Nitralloy analyses and nitriding treatments have recently been improved to such an extent that the cases are much more ductile than formerly without appreciable loss of hardness, and it is entirely safe to use these materials under any impact stresses that may be applied safely to case-hardened materials.

E. E. Thum.[9] The paper is hardly broad enough to cover the ground indicated in the title, since the author confines himself to locomotive parts and makes no mention of alloy steels used for rails. Furthermore, while he mentions many alloys used for various locomotives, he dwells particularly upon nickel steels and irons.

He is to be commended especially for emphasizing the fact that metallurgy has become so highly specialized that railway mechanical engineers should consult steel experts before they go very far in designing a locomotive that is to use heat-treated steels.

Further emphasis should be given to the fundamental difference between the application of heat-treated steels to automobiles and to locomotives. A locomotive requires steel in very much heavier cross-sections than does an automobile, and in handling such heavy forgings due regard must be paid to what metallurgists know as the "mass effect in heat treatment." Suppose one has a $^3/_4$-in. bar and a 3-in. bar of a certain steel (identical except for size) and gives them identical heat treatments. He then cuts the bars up into standard test pieces, and he will find that the properties of the 3-in. bar are not uniform, surface to center, and do not in general correspond to those of the test piece cut from the heat-treated small bar. This is a practical exposition of the "mass effect," and the reason for it is easily understandable when it is appreciated that the properties of a quenched and tempered piece of steel depend fundamentally on the state of dispersion of the hardening carbides in the iron itself, and from a practical standpoint the dispersion of hardeners depends upon the speed at which the metal is carried through the "critical" range. In a very bulky mass of steel it is obvious that the exterior surface will cool at a faster rate than the metal in the very interior; these differences are intensified when a bulky piece is drastically quenched, as in cold brine, with correspondingly great differences in the physical properties at different depths below the surface. Seasoned experience and sound judgment alike indicate that such a heterogeneous mass of steel is not as reliable as it might otherwise be.

The most practicable way to avoid this trouble in heat-treated heavy forgings is to make them of those alloy steels that are known as "air hardening." An air-hardening steel is one that does not require a rapid and drastic quenching in order to keep the hardening carbides in a properly dispersed condition. In other words, the rather slow and deliberate cooling which a hot piece of metal would experience when merely exposed to quiet air at room temperature is sufficient to retail the microscopic constituents of a good air-hardening steel in such a condition that the metallic aggregate at the end has enhanced physical properties.

It is therefore important that railroad engineers should be informed about those steels which show this air-hardening property to the optimum extent. Attention should be called to the nickel-chromium-molybdenum steel which has been so successfully used for heavy ordnance for the last 15 years, especially in England. These steels have probably not yet been made into railroad forgings, but their properties are so good that this neglect must only be due to the fact that mechanical engineers generally are not well enough informed about this type of alloy steels.

A recent report (No. 67) from the research department, Woolwich Arsenal, England, describes extensive experience and tests with these steels, the production of which is characterized by them as being "one of the most important metallurgical achievements of recent years." A typical composition for a large forging (such as a 12-in. gun tube), having a high yield point and relative absence of mass effect, is as follows:

	Per cent
Carbon	0.30
Silicon	0.15
Manganese	0.50
Nickel	2.50
Chromium	0.75
Molybdenum	0.50

Tests taken from one such heat-treated forging, 10-in. thick (to quote only one), and at various depths below the surface, fall within the following very narrow limits:

Ultimate strength, lb. per sq. in.	149,000 to 153,000
Yield point, lb. per sq. in.	126,000 to 137,000
Elastic limit, lb. per sq. in.	105,000 to 110,000
Elongation, per cent	17 to 19
Reduction in area, per cent	37 to 50
Brinell hardness	314 to 324
Toughness (Izod-impact number), ft-lb.	19 to 32

It will be noted that the maximum variation in hardness, surface to center, of such a large forging is only 10 points, whereas a nickel-chromium steel gun tube would be expected to have as much as 60 points difference in Brinell hardness, surface to

[9] Associate Editor, *The Iron Age*, New York, N. Y.

center. (Brinell hardness has a direct relationship to tensile strength.) The heat treatment given to this particular forging consisted of an anneal at 1600 deg. fahr., an oil hardening from 1550 deg. fahr., and a final tempering at 1200 deg. fahr. While this heat treatment is doubtless more extensive than locomotive constructors would like to give to engine parts, it should be remembered that this particular analysis of steel will respond properly to heat treatment when the rate of cooling through the critical range is as low as 5 deg. per min. This fact, of course, is responsible for the uniform properties of the material in such heavy sections, and excellent uniform strength and toughness may be expected from such low-alloy steels after a single heating and air cooling. Furthermore, a reheating, such as would be given from a hot box in service, would not destroy the physical properties, if the part were permitted to cool naturally in the air.

H. A. F. Campbell.[10] The writer has read the paper with interest. In fact, he has read it several times, and it has been a pleasure, because the paper is clear, concise, to the point, and above all very readable.

The writer recently rode from Washington to New York for the whole 236 miles on the pilot of the locomotive of the B. & O.'s fastest train. On the New York Division we were surely hitting some high spots as to speed. There is nothing very unusual about this, but here is the point—to ride on the front of a locomotive making 350 r.p.m. and watch the running gear, main rod, siderods, crosshead, and valve gear thrashing around one would probably feel that he did not quite see why any of it holds together at all. It has never failed to impress upon the writer the necessity for the most skilful design, finest material, perfect workmanship, constant and close upkeep of these very fast moving parts of a locomotive.

Now in regard to nickel steel for the running gear of a locomotive, the writer can speak with some amount of background and experience with nickel steels. In 1915 there was built by the Baldwin Locomotive Works a lot of 15 high-speed Pacific-type locomotives for the C., B. & Q. Railroad. These engines had 27 × 28 × 180/74. The siderods, main rod, main pins, main stub straps, and piston rods were made of nickel-chrome steel. The crossheads were very light and of special cast steel. The nickel-chrome steel was as follows:

Carbon	0.40
Manganese	0.70
Phosphorus	0.010
Sulphur	0.030
Nickel	1.50
Chrome	0.60
Ultimate strength	95,000
Elastic limit	65,000
Elongation, per cent	23
Reduction, per cent	60

Quenched in oil and drawn.

The greatest care was given to the design, the first materials the making of the steel, the forging of the parts, the machining of each piece, and the line-up and set-up in the final erecting. This set of running parts still ranks among the very lightest, for the loads carried, of any in America. It must be fankly stated that this was a special job. It was made just as near as possible 100 per cent throughout each and every process or operation. It was an experiment to show what could be done with very light parts and very high-grade steel. These 15 engines have been in high-speed service for 14 years. There have been some failures, of course, especially of the piston rods; but if these piston rods and crossheads had never had to be cut, without the slightest doubt the original piston rods would still be in service. Some of the original sets of main rods and side-rods are still running and all the sets gave ten years' service with practically no failures. Remember, these running parts were very light. Their history and service represent what can be done with a fine steel, if there is the desire, the determination, and the knowledge to do it. And today we can make an even better steel and forging. Much has been learned and developed since 1915.

[10] Baldwin Locomotive Works, Philadelphia, Pa.

The author has referred to three steels that are normalized and drawn or air-quenched and drawn:

Carbon Vanadium

Carbon	0.40–0.50
Manganese	0.75–0.90
Vanadium	Not less than 0.18
Ultimate strength	90–100,000
Yield point	60–70,000
Elongation in 2 in., per cent	22–28
Reduction, per cent	40–45

Carbon Nickel

Carbon	0.24
Nickel	2.58
Ultimate strength	83,000
Yield point	60,300
Elongation in 2 in., per cent	31
Reduction, per cent	60

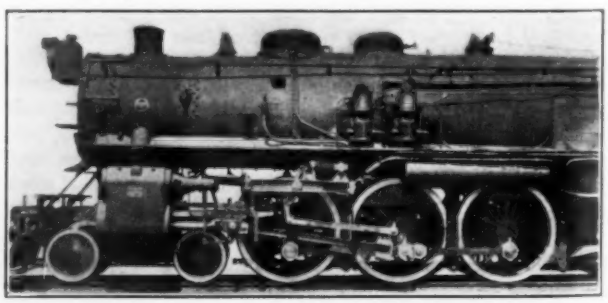
Carbon

Carbon	0.45–0.50
Manganese	0.50–0.85
Silicon	0.30
Ultimate strength	85–90,000
Yield point	50–55,000
Elongation in 2 in., per cent	22–24
Reduction, per cent	34

These three steels all are good. Actually there is not a great amount of difference between them.

Wristpins, piston rods, main rods, etc., have to withstand direct tension or compression, bending repeated and reversed, and impact loads, and all of these separately or combined. The steel is under constant fatigue stresses. Some of these parts get the initial crack—that is, the start of a fracture in compression or shear, not in tension at all. Elaborate tests are made for the tension qualities of a steel, when actually one should also study and know its compressive and shear qualities.

It is becoming recognized that the fatigue range, the endurance limit under various combinations of strains, is a function of the



ultimate strength of the steel, and to a much less extent to the elastic limit, elongation, and reduction of area.

That being so was the reason for the previous statement that the three steels are all equally good, one with the other. It is doubtful if the carbon-nickel steel has a fatigue range or endurance limit as good as the carbon-vanadium and carbon steels.

In this connection the writer has had some experience with locomotive wristpins and piston rods of a grade of steels with ultimate strengths very much higher than any of the steels considered by the author.

It might be mentioned that two of the hardest worked parts on a locomotive are the driving springs and the wheel tires. Both are higher carbon steels, with high ultimate strength and reduced elongation or reduction.

The first Norfolk & Western electric locomotives in 1915 produced jackshaft, main pin and siderod loads the like of which had never been dreamed of in nearly 90 years of steam-locomotive operation. It was a truly desperate situation. Unique methods were used to overcome and make these locomotives into working machines.

New jackshaft disks and driving wheel centers with much enlarged hubs were made. The main wristpin in the jackshaft disk, and the wristpins in the front and back drivers were made larger. Special high-carbon forged steel, oil-quenched and drawn, was used. This was a special steel from its inception to its finish, stock, casting, blooming, forging, heat-treating, and fina machining—a 100 per cent job. This forged steel was as follows:

Carbon	0.72
Manganese	0.65
Silicon	0.30
Ultimate strength	140,000
Elastic limit	90,000
Elongation, per cent	12
Reduction, per cent	20

Oil-quenched at 1450 deg., drawn at 1100 deg.

Shortly after the application of these new pins, they were slightly turned down and mild-steel hardened bushings were forced on. This was to avoid returning these pins at later dates.

An exact record of each of these pins is not available. However, they worked; they helped to make these locomotives a working proposition. After fourteen years, certainly, very many of these wristpins, if not perhaps every one of them, are still in service. They were of very high tensile steel, 140,000 lb. ultimate strength, elongation 12 per cent. And bear in mind, these pins were always subjected to the most terrific punishment.

Also, consider two sets of ten each of very high tensile locomotive piston rods now running on the Santa Fe Railroad, as follows:

Piston rods of carbon manganese steel

Carbon	0.51
Manganese	2.0
Silicon	0.33
Ultimate strength	140,000
Elastic limit	100,000
Elongation, per cent	14
Reduction, per cent	34

Oil-quenched and drawn.

Piston rods of nickel-chrome steel

Carbon	0.34
Manganese	0.60
Nickel	2.8
Chrome	0.79
Ultimate strength	131,000
Elastic limit	100,000
Elongation, per cent	15½
Reduction, per cent	31

Oil-quenched and drawn.

In regard to locomotive running-gear parts, it is best to keep one or two general points in mind. There is talk about repeated stresses and fatigue of metal in a rather loose way, 1,000,000 repetitions of a stress, and so on. In locomotive work that is a mere warming up.

The piston rod or crosshead key of a high-speed locomotive in making the one run of 236 miles between New York and Washington has 120,000 repetitions of stress, of varying intensity, put on them in the one trip. In ten days this is 1,200,000 repetitions; in 300 days it is 36,000,000 repetitions.

Therefore, for the modern steam or electric locomotive, the writer would say to go just as far as one can with these three moderate tensile steels with about 90,000 lb. ultimate strength.

But when a change from this class of steel has to be made, then it must be a real change, made whole-heartedly, not worrying about a few cents per pound in price or whether this or that shop can handle the new class of steel. It must be handled, that is all; organize to do it. We do not expect to or try to replace or retreat a driving-spring plate at every roundhouse on the road. It is done at one base shop. Also what in the world has price to do with absolute safety for a locomotive running at 90 m.p.h.? A few cents more per pound for the steel for the running gear for a locomotive costing a total of $110,000 is a small extra cost in comparison to security and safety.

Very high-tensile steels are going to be used more and more for locomotive running gear, and for the very best reason in the world—because they have to be.

The writer's company has to help to design a main rod, and to do all the making of it, to withstand an initial normal piston load of 210,000 lb. Just what would one make the design, the steel, and the manufacture of such a rod? It is a nice problem and something to think about.

G. M. Eaton.[11] There is a real need for a complete and authoritative analysis of Damascus sword blades. It has been known for many years that they contained molybdenum, and now it is learned that they also had a nickel content. It seems unfair to exclude vanadium, tungsten, titanium, and other alloying elements from this roll of honor.

After hearing Mr. Campbell's discussion, the writer takes occasion to congratulate industry at large on the existence of a machine in which the design, material, treatment, fabrication, performance, etc., are all absolutely 100 per cent. This is the only instance which has come to our attention where this goal was achieved in any single one of the particulars noted.

In connection with the reference to "endurance limit," the writer would call attention to the fact that all the fatigue-test results published in this country and which have come to our attention are based on test pieces so small that residual stress is largely removed in the machining operation. Furthermore these test pieces are provided with a surface polish far beyond that usually given to structural elements.

Recent English publications give endurance limits for test pieces carrying the surface as finished by hot rolling operations. These results are just about half the values we have been using in this country. One must emphasize strongly the need of caution in using endurance-limit values. It should be known how well the conditions surrounding the test and the preparation of the test piece represent the preparation and service of the actual article.

Work is now under way in this country on fatigue testing, not only with hot-rolled surfaces, but also on large sizes and with a variety of thermal treatments.

We concur with the conviction that where carbon steel is delivering the goods its use is to be preferred to the use of alloy steel. When carbon steel fails in an epidemic manner, recourse to alloy steel is often the best solution, but there are the difficulties such as the demand for careful thermal treatments, records of what parts are of alloy steel, etc.

The writer finds that the proper psychological set-up exists when the railroad comes to the alloy industry for help. The alloy-steel installation is then removed from the orphan class

[11] Commercial Engineer, Molybdenum Corporation of America, Pittsburgh, Pa. Mem. A.S.M.E.

and becomes a member of the family, and its success is far more assured than when the trial is made without the enthusiasm of those in a position to devise and enforce the precautions essential to success.

Referring to nitrided journals on main driving axles, the writer is opposed to any driving axle, at least on passenger power, in which a brittle surface exists on the main body of the axle. A beautiful solution exists, however, when the axle design is modified in a manner which permits the shrinking of a nitrided bushing over the journal face. This gives all the advantage of the nitrided journal surface, together with a properly ductile axle as a foundation.

The railroads are turning to alloy steel here and there where they have gone as far as they can with carbon steel. This is a healthy condition, and as the procedure evolves itself alloy steels will find their logical railroad applications.

Dr. A. Giesl-Gieslingen.[12] America is far in the lead in the use of alloy steels in locomotive construction. Austria got



along entirely without them until two years ago, when the most powerful European passenger locomotive of the inverted Mountain or 2–8–4 wheel arrangement was developed. The main rod of this engine, for example, represented quite an interesting problem. It was originally planned to work upon the second pair of drivers with a conventional length of rod, but investigations on the effect of the vertical component of the piston thrust upon the rails revealed excessive increases over the wheel load at certain crank positions. These investigations suggest, by the way, the probable reason for the unexpectedly high track maintenance with some existing three-cylinder designs, and led to the adoption of a two-axle drive, like in American practice, in the latest experimental three-cylinder locomotive for the Austrian Federal Railways. In the case of the 2–8–4 two-cylinder engine with 107,000 lb. piston thrust, the use of the second pair as main drivers would have resulted in a fluctuation of wheel load between 80 and 180 per cent of the weight on these drivers during half a revolution, hammering upon the rails five



times per second when the engine is pulling heavy trains up the maximum grade at 35 miles per hour. Working upon the third pair of drivers cut these variations exactly in half and made this heavy engine easier on the track than some of its lighter predecessors. This necessitated a 14-ft. main rod, the longest in the world, and the use of alloy steel in this rod seemed imperative. It was designed with extremely light sections, weighing only 850 lb. without brasses. At 75 miles per hour the rod swings about $\frac{1}{2}$ in. vertically, deviating $\frac{1}{4}$ in. from its geometric center line. Here the question of fatigue enters, but this rod has a greater safety than many others in service.

It will pay to study locomotive designs from this viewpoint to reduce track maintenance, and there is one of the cases where high-grade alloy steel will help to effect considerable economy.

Author's Closure

In the discussion it has been twice remarked that the scope of this paper was not broad enough and, specifically, did not include rails or springs. The field of the paper was very definitely indicated and limited by the committee, and the author simply followed with bucolic contentment the paths outlined.

It has been asked what is the European practice in regard to the use of alloy steel. From necessarily brief observations the author would say that at present the railroads in Europe do not use alloy steel to the same extent that they are used on this continent. Alloy steels are just beginning to be used for boilers. The recent high-pressure locomotive built in England employs nickel steel for the boiler. Very little alloy steel is used for frames, as the frames in European practice are usually built up from rolled plates. When alloy steels are used for forgings, such as axles, piston rods, main rods, and siderods, they are more often than not quenched and tempered, although the tendency is, as in this country, toward the normalized steel. The types of alloy steels most used are nickel, nickel-chrome, and nickel-chrome-molybdenum; in fact, all that came to attention were one of these three types. The nickel-chrome-molybdenum has been used to some extent for railway forgings in England in the quenched and tempered state. This steel has the advantage of giving very nice tensile properties, together with

[12] Vienna, Austria.

depth hardness and freedom from temper brittleness. As far as is known, it has not been largely used in the normalized state, but would seem to be a very good steel.

The most striking difference in European practice was that of lubrication, as there the tendency is all toward forced and automatic oil lubrication in place of our generally unsatisfactory hard-grease lubrication.

Mr. Norris cites data which tend to show that the figures given in the paper are too low. It was the intention in quoting specifications and tensile results to give an adequate picture of what might be obtained by using alloy steels, and the results quoted are not to be considered by any means the ultima thule. Case after case could have been quoted where higher results had been obtained. It should be particularly noted in connection with the figures on low-carbon nickel steel that the highest possible tensile strength is deliberately sacrificed in order to obtain maximum toughness, ductility, and impact resistance. If strength alone were the criterion, it would have been possible by a slight readjustment of the elements in this steel, such as carbon, to far exceed any figures quoted in the discussion. In this connection, the data given by Mr. Pascoe on water-quenched low-carbon nickel steel are extremely interesting and merit attention.

Mr. Winterrowd by his query introduces a very wide subject. The variation from billet to billet of steels made to the same specification, or even from the same heat, involves the history of the steel from the time it was melted in the furnace until the time it was finally finished-machined. These differences may arise from improper teeming into the mold, from "ingotism" or large crystal structure in the ingot, from cracking of the ingot, from improper cooling, from irregularities in the mechanical working, from inequalities of heat treatment, and from a number of other sources. Variations of this sort bring into prominence the quality factor which has been referred to in the paper.

The Stug System of Pulverized-Fuel Firing on Locomotives

By R. ROOSEN,[1] KASSEL, GERMANY

The object of the system described in this paper is to solve the problem of firing locomotives with coal dust of any description. The author tells of the advantages that can reasonably be expected from use of such a system and of some of the difficulties that make pulverized-fuel firing for locomotives a severe problem.

Test results with lignite fuel are given and the methods and equipment used by the German State Railways are described. Particular emphasis is laid on the economical side of using pulverized fuel in engines.



THE numerous advantages which pulverized-fuel firing had given in stationary plants strongly suggested its extension to locomotives, considering that a number of advantages in railway operation and economics were to be expected. Among those aimed at, the following are particularly worthy of mention:

(1) Cutting down the fuel bill, which result is achieved by:

(*a*) The possibility of using low-grade, cheap fuel, particularly such as would not be suitable for grate firing

(*b*) Reducing the quantity of fuel consumed, as pulverized-fuel firing permits of controlling the fire according to the actual output of the locomotive

(*c*) Reduction of standby losses to a minimum and thus avoiding blowing off of safety valves

(*d*) Better utilization of fuel, owing to improved boiler efficiency.

(2) Savings in the roundhouse, owing to considerably reduced wage bill for cleaning ashpan, smokebox, and pits.

(3) Quicker readiness for service, as boiler will be steamed in considerably less time.

(4) No obstructions to draft by clinker as on the grate of standard engines, and consequently increased locomotive mileage.

(5) Possibility of firing very large quantities of fuel in a more economical way than with any other type of mechanical stoking; fireman fatigue completely eliminated.

(6) No sparking at all, avoiding danger of conflagration; no smoke annoyance.

These advantages have instigated considerable experimenting with a view to applying pulverized-fuel firing to locomotives. The attempts made in the United States and elsewhere, such as in Brazil, Sweden, and England, are too well known to need a résumé. In all these cases, however, difficulties more or less prevented the adoption of pulverized-fuel firing on a large scale. Such difficulties were due to the fact that locomotive boilers with their small furnaces present less favorable conditions than stationary boilers or furnaces. In order to ensure sufficient steaming, the locomotive furnace must be stressed to about 10 times what was usual in stationary plants. Either the requisite firebox stress was not attained or the result was the formation of slag on the tube sheet, which soon caused a decrease in steam generation. This may have been due to the fact that stationary-boiler practice with pulverized-fuel firing was applied to locomotive boilers without due consideration being given to their peculiar conditions of service. Either the types of burners employed or the method of supplying air did not prove suitable for generating in the relatively small firebox the amount of heat necessary to develop the requisite quantity of steam or to ensure combustion under such conditions as would preclude trouble with the slag. Any departure from the normal firebox, however, was not advisable, because it was very important, in order to introduce pulverized-fuel firing without considerable initial cost, to abide by the approved pattern, with a view to the easy conversion of existing locomotives into dust-fired engines.

Moreover, the form of the firebox brick lining, which was deemed necessary in a too close imitation of stationary practice, was a delicate problem. The very high temperatures in the firebox resulting from excessive lining, combined with the action of the long, sharp pin flames produced by the types of burners employed, caused a progressive destruction of the brickwork. The complicated design of the lining also made it very apt to crumble and break down under the influence of running shocks. All this entailed continuous and expensive repair work.

Another problem to be faced was the limited space on the locomotive and tender available for the pulverized-fuel equipment, which of course must be arranged so as to combine reliability with economy.

The aforementioned difficulties made pulverized-fuel firing on locomotives a very difficult problem with which to cope. On the other hand, there was sufficient incitement to tackle it anew and bring about definitely satisfactory results. It was with this object in mind that the Stug (Studiengesellschaft für Kohlenstaubfeuerung auf Lokomotiven) was formed when after the war economical considerations in Germany urged the use of low-grade fuel for locomotive firing, particularly lignite, which was available in abundance. The Stug includes the following firms:

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[1] Chief Engineer, Henschel & Sohn A. G. The author was born in Hamburg on October 13, 1901. He studied machine building at the Dresden Technische Hochschule. In 1925 he joined the firm of Messrs. Henschel & Sohn A. G., of Kassel, where he was put in charge of new locomotive design and tests, chiefly in connection with turbine, Diesel, and coal-dust fired engines. In 1929, Messrs. Henschel & Sohn appointed him chief engineer in charge of the Research Department. At the same time he was selected to superintend the activities of the "Studiengesellschaft für Kohlenstaubfeuerung auf Lokomotiven" (Research Society for Pulverized-Fuel Firing on Locomotives) and, in 1930, of the "Stug Patentverwertung G.m.b.H." (Stug Patents Exploitation, Ltd.). Mr. Roosen's duties in connection with the "Stug" have taken him several times into foreign countries; thus he delivered a lecture on pulverized-fuel firing before the Institution of Locomotive Engineers at the Glasgow meeting in 1929.

Contributed by the Railroad Division and presented at the Annual Meeting, New York, N. Y., Dec. 1 to 5, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

A. Borsig, G.m.b.H., Berlin-Tegel
Hanomag, Hannover-Linden
Henschel & Sohn A.G., Kassel
Fried. Krupp A.G., Essen (Ruhr)
Berliner Maschinenbau A.G., vorm. L. Schwartzkopff, Berlin,

as well as the German coal and lignite syndicates:

Mitteldeutsches Braunkohlensyndikat, Leipzig
Ostelbisches Braunkohlensyndikat, Berlin
Rheinisches Braunkohlensyndikat, Köln am Rhein
Rheinisch-Westfälisches Kohlensyndikat, Essen (Ruhr)
Oberschlesisches Steinkohlen-Syndikat, Gleiwitz.

These are in cooperation with the German State Railways, the offices being at Kassel on the premises of Henschel & Sohn A.G., where the study and research work were carried out. It was the Stug's aim to solve the problem of firing coal dust of any description in locomotives, stationary plants being included later on.

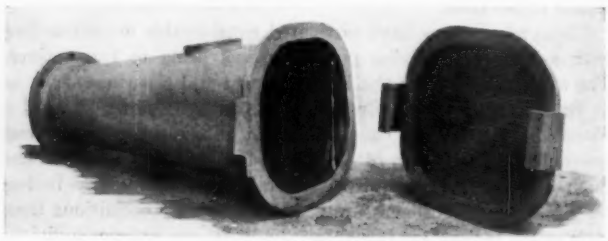


FIG. 1 STUG BURNER, NEW DESIGN

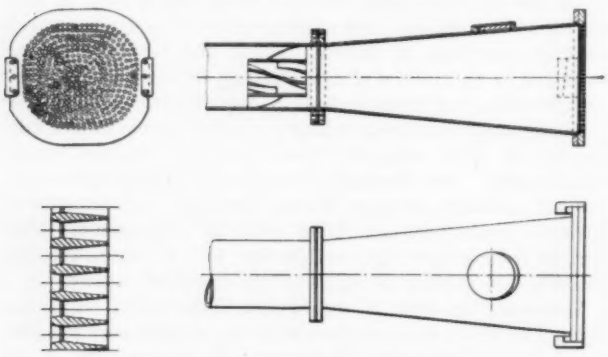


FIG. 2 ARRANGEMENT OF BURNER

As far as locomotives were concerned, the experiments were to evolve a system which would combine the following features:

A rate of evaporation of 12.3 lb. of steam per square foot of heating surface per hour
Variation of burner output within the wide range between maximum stress and minimum stress
High boiler efficiency and prevention of honeycombing so as to ensure continuous operation without trouble due to slag deposits
Simple and highly resistive brick lining
Utmost working reliability of the whole equipment.

The work was systematically carried out on the largest possible scale, since there was a clear understanding that real success could be attained only by making a sound combination of theoretical investigation and experimental work.

In order to avoid from the inception the shortcomings of earlier experiments, two principal requirements had to be fulfilled in the first place:

(1) Shaping the flame so as to fill the whole firebox and avoiding the pin flames which deteriorate the tube sheet or brick lining.

(2) Obtaining a high specific intensity of combustion for peak loads of about 230,000 B.t.u. per cu. ft. of firebox volume, and even more in particular cases, i.e., about 10 times the amount obtained in stationary plants.

Experimentation, properly speaking, commenced after thorough preparatory work. The main task was to develop a type of burner suitable for the combustion of pulverized fuel in a locomotive firebox. The result was, after some simplifications of the shape, a burner such as is illustrated in Fig. 1, which shows the definite form. This burner, on account of its action, is called a "spray burner," and it is based on the Stug's principle of subdividing the injected mixture to the largest possible extent. It consists essentially of a truncated hollow cone, the front end of which is closed by a plate having a very large number of nozzle-shaped holes, whereas the small rear end joins a mixing device for the coal dust and air mixture entering at this point (Fig. 2). The dust and air mixture is thus spread into a considerable number of individual jets which are ignited almost immediately in front of the burner plate, and this causes the formation of a diffused, ball-shaped flame. Clogging of the numerous holes by dust was never experienced. The burner or burners, which are thus constructed in a very simple manner, are so arranged that the spray plates come nearly flush with the firebox back plate, while the burner bodies are outside. The burner bodies therefore remain cold when in operation; the spray plate, which is exposed to radiating heat, being cooled by the coal dust and air mixture. Special cooling of the burners can thus be dispensed with. If one of the burners is out of operation, it is cooled during that time by a small current of pure air. That this system of air cooling is entirely sufficient, is illustrated by Fig. 3, the burners shown having been taken out of a locomotive boiler after having stood a very large number of tests.

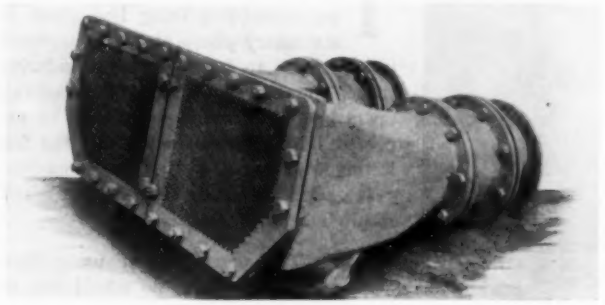


FIG. 3 STUG BURNER, OLD DESIGN

In order to achieve correct design of the burner and furnace, a large number of questions had to be studied, such as the process of combustion, the intensity of combustion, influence of the shape and dimensions of the brick lining on combustion, etc. Thus, the intensity of combustion, expressed in thermal units per cubic foot of firebox volume, is inversely proportional to the gas volume developed during the time of combustion of the dust. The latter must not remain in the firebox for less time than it takes for complete combustion, and the gas speed in the firebox, therefore, must not exceed the velocity of combustion of a dust grain. The gas volume developed during the time of combustion must consequently remain in the firebox until combustion of the dust grain is completed. The gas volume, however, increases with increasing temperature, i.e., lowering the temperature would permit of increasing the intensity of combustion, and this can be effected by reducing the brick lining.

TABLE 1 TESTS MADE IN THE ROTHENDITMOLD TESTING PLANT ON LIGNITE FUEL

Date	6-24-25	6-24-25	6-5-25	6-23-25
Test No.	76	76	72	74
Lower heating value, B.t.u. per lb.	9360	9360	9360	9360
Fuel consumption, lb. per hour	1850	2290	2625	3260
Firebox stress, B.t.u. per cu. ft. per hour	1.2×10^5	1.48×10^5	1.69×10^5	2.1×10^5
Evaporation, lb. per hour	9060	11080	12100	14350
Temperature of feedwater, deg. fahr.	51.8	51.8	51.8	51.8
Coefficient of evaporation	4.88	4.83	4.61	4.38
Evaporation of heating surface, lb. per sq. ft. per hour	9.35	11.42	12.50	14.80
Boiler pressure, lb. per sq. in.	85.3	85.3	85.3	85.3
Average temperature of superheated steam, deg. fahr.	742	726	689	698
Average temperature of flue gas in smokebox, deg. fahr.	738	706	698	717
Analysis of flue gas: CO_2, per cent	15.6	15.6	14.9	14.2
Analysis of flue gas: O_2, per cent	...	...	...	...
Analysis of flue gas: CO, per cent	...	...	...	...
Boiler efficiency, determined from flue-gas losses, per cent	71.7	73.1	72.5	71.3

Free heating surface in firebox (not brick-lined), sq. ft.	100.3
Heating surface in tubes, sq. ft.	867.4
Total heating surface, sq. ft.	967.7
Firebox capacity, cu. ft.	144.7

$$\frac{\text{Free heating surface in firebox (sq. ft.)}}{\text{total heating surface (sq. ft.)}} = \frac{100.3}{967.7} = \frac{1}{9.65}$$

$$\frac{\text{Firebox capacity (cu. ft.)}}{\text{total heating surface (sq. ft.)}} = \frac{144.7}{967.7} = \frac{1}{6.68}$$

been equaled by any other type of stoking on locomotives (Table 2). Indeed, this is more than a locomotive boiler would continuously stand. On analysis the flue gases were found to contain 13.5 per cent carbon dioxide and 5 per cent oxygen. The smoke emitted from the chimney was transparent and showed a grayish hue. The fuel was a commercial quality of lignite dust developing about 9000 B.t.u. per lb. when ground to about 20 per cent residue on a 170-mesh screen.

After these excellent results

TABLE 2 TESTS MADE IN THE MITTELFELD TESTING PLANT ON LIGNITE FUEL

Date	3-22-28	4-24-28	6-26-28	5-18-28	11-11-27	11-11-27
Test No.	343	354	379	362	283	284
Lower heating value, B.t.u. per lb.	10060	8950	8500	9420	8725	8725
Fuel consumption, lb. per hour	4380	5390	6080	6180	7680	8500
Firebox stress, B.t.u. per cu. ft. per hour	1.98×10^5	2.17×10^5	2.32×10^5	2.61×10^5	3.10×10^5	3.33×10^5
Evaporation, lb. per hour	26150	29600	30620	34200	36960	40500
Temperature of feedwater, deg. fahr.	212	212	206	210	212	212
Coefficient of evaporation	5.96	5.50	5.03	5.53	4.82	4.77
Evaporation of heating surface, lb. per sq. ft. per hour	12.52	14.18	14.70	16.40	17.70	19.40
Boiler pressure, lb. per sq. in.	170.7	170.7	167.8	170.7	163.6	169.4
Average temperature of superheated steam, deg. fahr.	770	689	768	711	644	655
Average temperature of flue gas in smokebox, deg. fahr.	635	646	638	696	882	912
Analysis of flue gas: CO_2, per cent	14.7	15.1	14.85	14.3	13.5	13.1
Analysis of flue gas: O_2, per cent	2.65	3.1	2.0	2.6	5.0	4.8
Analysis of flue gas: CO, per cent	0.25	0.40	0.20	0.33	...	...
Boiler efficiency, determined from flue-gas losses, per cent	73.0	72.9	73.25	70.8	65.2	64.7

Free heating surface in firebox (not brick-lined), sq. ft.	139.9
Heating surface in tubes, sq. ft.	1945.1
Total heating surface, sq. ft.	2085.0
Firebox capacity, cu. ft.	222.5

$$\frac{\text{Free heating surface in firebox (sq. ft.)}}{\text{total heating surface (sq. ft.)}} = \frac{139.9}{2085.0} = \frac{1}{14.9}$$

$$\frac{\text{Firebox capacity (cu. ft.)}}{\text{total heating surface (sq. ft.)}} = \frac{222.5}{2085.0} = \frac{1}{9.36}$$

Shortening the combustion period of the dust grain has the same effect. It can be obtained, besides, by proper mixture of the dust and air in the burners, as mentioned before, by increasing the fineness of milling of the coal. This process, however, if pushed beyond commercial practice, may become uneconomical, so that the use of this method is curtailed. Thus the Stug uses a degree of fineness of about 15 to 25 per cent residues on a 170-mesh sieve for lignite and about 10 to 20 per cent for coal containing a low percentage of volatiles. All this investigation work required a large number of tests. Under these conditions the Stug obtained, as early as 1925, in a locomotive boiler of 967.7 sq. ft. heating surface, an evaporation from cold feedwater of 14.3 lb. of steam per square foot of heating surface, combustion being entirely satisfactory (Table 1).

When the German State Railways, on the strength of these results, called upon the Stug to obtain a rate of evaporation of 12.3 lb. of steam per square foot of heating surface per hour in the G-12 boiler, the desired result was obtained only after further experimental work. The difficulty was that this boiler has a firebox considerably smaller in relation to the heating surface than the boiler tested in the first place (ratio 1 to 9.65 as against 1 to 14.9). It thus became necessary to raise the intensity of combustion to more than 237,000 B.t.u. per cu. ft. per hour. The brick lining was actually reduced to a minimum, and was just sufficient for the heat from the incandescent lining below the brick arch to be radiated back to the burner, and to protect the casing which has taken the place of the ashpan. Under these conditions the Stug even succeeded in intermittently raising the intensity to about 316,000 B.t.u. per cu. ft. per hour and the steam generation to well above 20.5 lb. per sq. ft. of heating surface per hour, which result, to the author's knowledge, has never were obtained, the German State Railways placed an order with Henschel & Sohn, one of the members of the Stug, to fit a coal-dust burning apparatus on two heavy 2-10-0 type superheated freight engines of the G-12 class.

Fig. 4 gives a general idea of the pulverized-fuel burning equipment of these engines. The German State Railways G-12 class is a three-cylinder engine with a heating surface of 2100 sq. ft. and a grate area of 42.0 sq. ft. The tender is of the six-wheeled type, and when converted retained the existing frame. Two burners of the type previously described are arranged below the firebox back plate, the spray plate having about 1900 holes and allowing the passage of about 3300 lb. per burner per hour. The ashpan is replaced by a casing suspended from the foundation ring. This casing is lined all over with firebrick, which radiate the heat stored in them back to the burners and thus assist in igniting the coal dust and air mixture. The brick lining of the wall opposite to the burners, below the brick arch, serves the same purpose. Apart from this, the firebox walls, nearly down to the foundation ring, are without any lining. This arrangement makes the whole of the surface in contact with the water highly evaporative and further affords easy observation of the staybolts. In the bottom of the casting a small auxiliary burner is provided, the operation of which is independent from the main burners. The front part of the casing is fitted with a bottom slide, worked from the fireman's side of the cab. Apart from this, the locomotives have not undergone any noteworthy modifications.

As mentioned before, the tender frame with wheels and axles remains unchanged. The water tank, of 3.740 gal. capacity, is of the horseshoe type. The usual coal bunker is replaced by the pulverized-fuel reservoir having a capacity of about 6.4 tons

and is constructed as a perfectly closed container with sloping sides. This shape is preferable to a cylindrical container, because it makes for a steady flow of the coal dust and does not allow it to rest in the lower portion of the container. For the same reason the container is welded and not riveted, so as to avoid projecting edges. In addition, stirring nozzles are provided in the container sides. The container is supported on the water tank at four points, and can easily be lifted as a unit. It is provided with three filling apertures in the top, which also give access for occasional inspection. As a rule, one of these openings is sufficient for filling purposes.

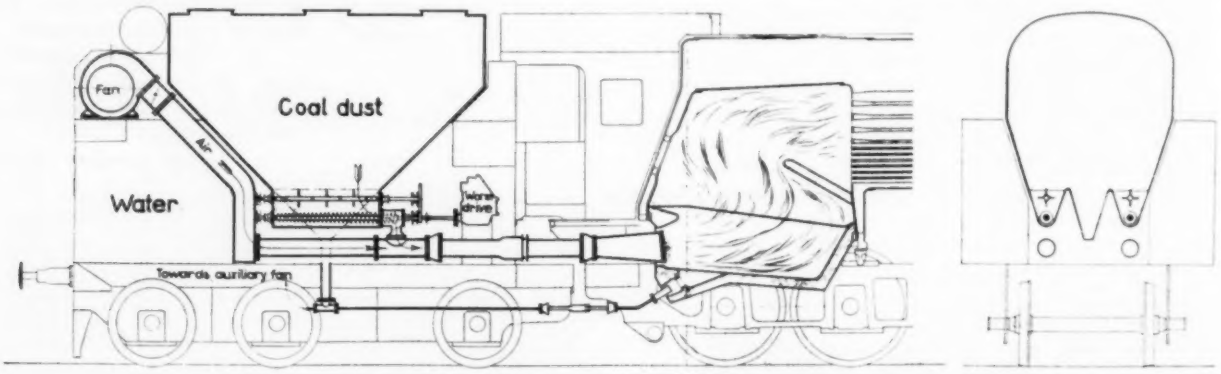


FIG. 4 LAYOUT OF A STUG LOCOMOTIVE, ORIGINAL DESIGN

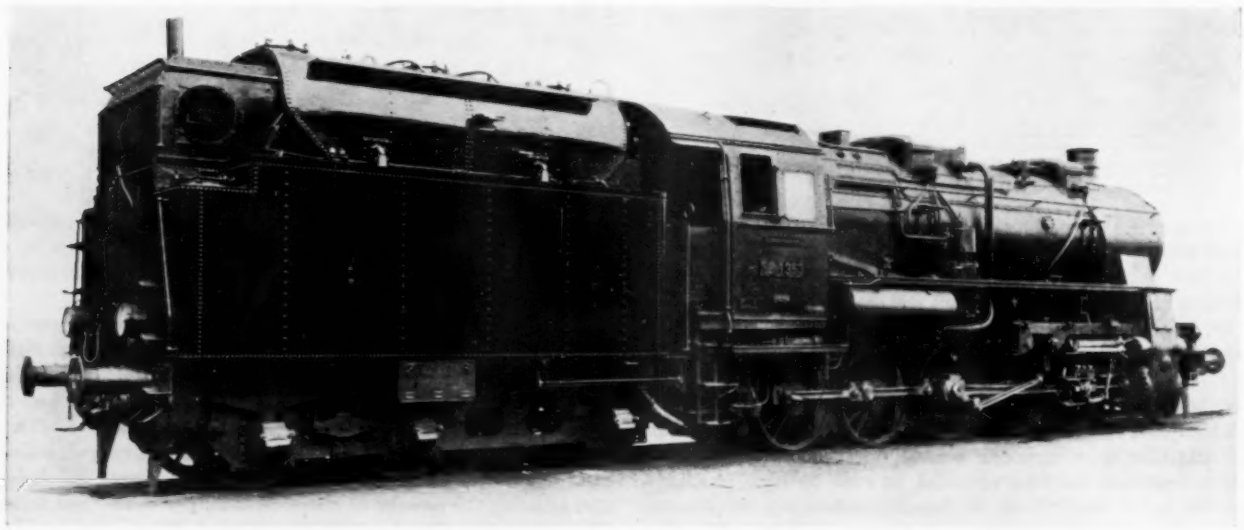


FIG. 5 COAL-DUST FIRED ENGINE NO. 58-1353

At the base of the container are three trough-shaped feedways, those on the outside housing the conveyor worms for the two main burners, while the conveyor screw for the auxiliary burner is lodged in the small central trough. These worms convey the coal dust toward an opening, through which it pours down into the air stream from the blowers. These worms can be clutched and declutched separately.

At the rear end of the water tank is the blower which supplies the air for combustion, and it should be noted that in this first lot of locomotives all of the air necessary for combustion is furnished by the blowers. This method keeps the excess of air in the firebox down to a minimum and ensures maximum boiler efficiency. The blowers are coupled to the turbine shaft, which revolves at a maximum speed of 4500 r.p.m. and operates on saturated steam taken from the dome of the boiler. From the blower the air flows through two separate pipes toward each burner, and on its way mixes with the coal dust conveyed by the worms. The air pipes, which terminate at the burners on the locomotive, are made flexible between the engine and tender by means of ball joints and stuffing boxes, and this arrangement has stood perfectly the test of actual service. The air speed in the pipes varies between 50 and 150 ft. per sec., more or less, according to the output of the locomotive.

The conveyor screws are driven by a small fast-running steam engine, which also operates on saturated steam. It is of the three-cylinder uniflow type, with inside admission piston valves, its speed being controlled by varying the degree of cut-off. A governor prevents the maximum speed from exceeding 500 r.p.m. The steam engine is geared to a small fan which supplies the combustion air to the auxiliary burner.

Admission of fuel to the main burners is controlled by varying the number of revolutions of the steam motor (within a speed range of about 1 to 5), and consequently the worm speed and the quantity of fuel conveyed by the worms. The same applies to the supply of air, which is regulated by varying the number of revolutions of the blower or throttling the admission of air. All of the controls are so interlocked as to make them foolproof. Thus the worms cannot be started before the blowers are set to work, and vice versa, so that clogging of the tubes with coal

TABLE 3 TESTS MADE IN THE MITTELFELD TESTING PLANT ON LIGNITE FUEL

Date	10-11-29	1-10-10	9-25-29	8-29-29	1-9-30	10-18-29
Test No.	25	34	18	15	33	28
Lower heating value, B.t.u. per lb.	9604	9366	9364	9432	9366	10052
Residues on 170-mesh screen, per cent	23.96	17.60	17.18	19.20	17.60	28.32
Fuel consumed, lb. per hour	1415	2000	3197	3792	4520	4211
Firebox stress, B.t.u. per cu. ft. per hour	0.606×10^6	0.836×10^6	1.33×10^6	1.6×10^6	1.89×10^6	1.895×10^6
Evaporation per hour, lb. per hour	9017	12081	19048	23149	26279	26522
Temperature of feedwater, deg. fahr.	208	201	210	217	205	212
Coefficient of evaporation	6.37	6.04	5.97	6.10	5.82	6.30
Evaporation of heating surface, lb. per sq. ft. per hour	4.32	5.80	9.12	1.11	12.6	12.68
Boiler pressure, lb. per sq. in.	201.9	199.1	200.5	201.9	201.9	201.9
Average temperature of superheated steam, deg. fahr.	639	651	714	711	738	741
Average temperature of flue gas in smokebox, deg. fahr.	554	576	639	642	705	709
Analysis of flue gas: CO_2, per cent	13.2	13.0	12.9	14.8	13.8	14.4
Analysis of flue gas: O_2, per cent	6.0	6.4	6.4	4.4	5.6	5.0
Analysis of flue gas: CO, per cent	0.0	0.0	0.0	0.1	0.1	0.1
Boiler efficiency, determined from flue-gas losses, per cent	77.2	76.2	76.7	77.2	75.8	76.0

Free heating surface in firebox (not brick-lined), sq. ft.	131.6
Heating surface in tubes, sq. ft.	1945.1
Total heating surface, sq. ft.	2076.7
Firebox capacity, cu. ft.	211.9

$$\frac{\text{Free heating surface in firebox (sq. ft.)}}{\text{total heating surface (sq. ft.)}} = \frac{131.6}{2076.7} = \frac{1}{15.8}$$

$$\frac{\text{Firebox capacity (cu. ft.)}}{\text{total heating surface (sq. ft.)}} = \frac{211.9}{2076.7} = \frac{1}{9.79}$$



FIG. 6 STUG G-12 LOCOMOTIVE, WITH DYNAMOMETER TRAIN

dust can never occur. When the locomotive is worked at less than half its full output, one of the burners is cut out. The nozzle plate of the idle burner is kept cool by a small air current being allowed to pass through it.

Both engines (Fig. 5) were first tried on several runs on the German State Railways' lines near Kassel. Thus schedule freight trains were hauled on the section from Kassel to Eichenberg, which has numerous curves and long inclines of 1 in 100. The weight of these trains was about 1200 to 1300 tons. On level track it was generally possible to run with only one burner in action, while on the heavy gradients, when both burners had to be operated, the engine was working at its full output of about 1400 hp. at the tender drawbar.

These trial runs fully demonstrated that the engines came up to all expectations as to their adaptability to running conditions, simplicity of operation, and reliability of the pulverized-fuel burning equipment. Full steam pressure could easily be maintained, and there was no difficulty in preventing steam from blowing off when passing from gradients to level or down grades. When running down steep gradients, both of the burners could be cut out, so that the auxiliary burner alone was in operation. When restarting the main burners, ignition was readily made by the auxiliary burner flame.

These trial runs were carried out on lignite dust developing about 9000 B.t.u. per lb. Combustion of the dust was perfect, the flue gases emitted through the chimney were colorless, and even on night runs no sparking was observed. Even while the engine was running very slowly, so that the exhaust puffs succeeded each other at relatively long intervals, there was an unimpeded flow of the flue gases.

On the strength of these results, one of these engines was assigned in May, 1929, to the Halle district of the German State Railways, where it has been in service ever since, with a considerable saving of fuel and furnishing a valuable occasion for collecting road experience. Particulars in this respect will be given in connection with other G-12 class engines adapted for the Stug system later on and likewise assigned to the Halle district. The economical success achieved will also be dealt with.

The other of these two engines was submitted to a series of thorough trial runs by the German State Railways' testing department at Grunewald (near Berlin), during the summer and fall of 1929. On such trial runs, the engine is coupled to a dynamometer car with a brake locomotive in the rear. The brake locomotive compresses air in its cylinders, which is exhausted through the chimney, so that the resistance can be adjusted to any desired amount. The engine under trial can therefore be examined with constant output and for any distance, independent of road conditions. All factors of interest, such as fuel and water consumption, boiler efficiency, temperature, and composition of flue gases, can thus be checked at various speeds and compared with each other. The runs were made under conditions varying from no-load to top boiler stress of 12.3 lb. per sq. ft. per hour. The dust consumption is determined by weighing the tender before and after the run.

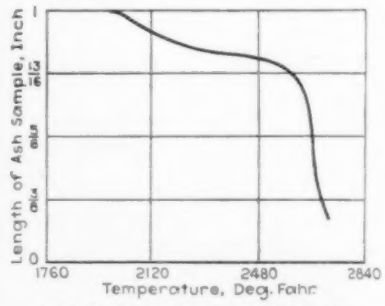


FIG. 7 SLAG MELTING DIAGRAM

The rate of coal-dust consumption and the boiler efficiency gave entirely satisfactory results. In all of these runs, the whole of the air required for combustion was injected through the burners (primary air supply), an improvement of the boiler efficiency being expected as against drawing part of the air direct through the ashpan into the firebox (secondary air supply). It was indeed possible to reduce the excess of air in combustion to about 20 per cent, corresponding to a CO_2 content of about 15 per cent, combustion being very satisfactory. It appeared, however, that with varying loads as experienced in actual service the advantage of introducing 100 per cent of the air for combustion as primary did not amount to much. Therefore, simultaneously with the trials of the first two engines by the State Railways, the Stug proceeded with a series of experiments on its test stand at Kassel, during which part of the air was blown through the burners and the remainder was drawn in through the ashpan. This method was necessary for the burning of hard-coal dust, which was then under trial at Kassel, and it furnished conclusive results also with lignite dust. On the basis

of these results obtained at Kassel, the Grunewald engine was submitted to another series of tests with part of the air drawn in through the ashpan (Fig. 6). The results were nearly the same as in the former series of tests, that is, entirely satisfactory. In order to furnish a basis for comparison with a conventional type engine, a normal grate-fired class G-12 engine was put to test under the same conditions. The boiler efficiency of the coal-dust fired engine was around 78 per cent under all loads, which, in the case of top load, was about 9 per cent above the grate-fired engine, while with small loads there was less difference. The heat expenditure in the fuel, related to the drawbar horsepower, was accordingly 9 per cent lower with peak loads. The steam consumption of the auxiliary machines on the tender is of course included. It amounted to about 5 per cent of the steam generation of the boiler. The combustion of the dust was complete. The composition of the flue gases will be seen from Table 3, which gives figures obtained in the course of trials made with the Stug system under loads as applied during the Grunewald runs.

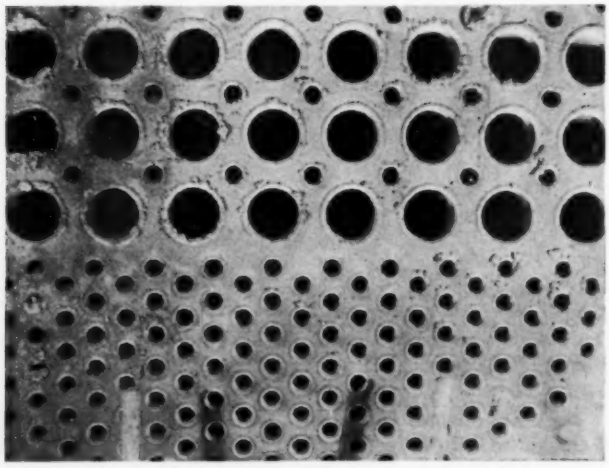


FIG. 8 TUBE SHEET AFTER HARD-COAL DUST TEST

After these tests had been carried out to entire satisfaction, the Grunewald engine was also assigned to the Halle district for regular service.

While the two aforementioned engines were undergoing trials by the State Railways, experiments on the test stand at Kassel were continued. The aim was to ascertain to what extent manufacturing could be simplified and cheapened. The tests chiefly bore on the possibility of driving the blowers and conveyor worms by one turbine, thus eliminating the steam motor which had been provided at the State Railways' request for the worm drive. It appeared that this simplified drive succeeded well if the air and dust supply were regulated so as to give a correct proportion at any turbine speed. Control of the furnace output from top load to minimum load (a range of about 1 to 8) was also obtained by just varying the turbine speed, one burner being cut out in the case of smaller loads. The auxiliary burner worm and blower, too, could be dispensed with in this way, since no-load performance of the engine could be maintained with one main burner in gear at reduced turbine speed. The equipment was thus greatly simplified.

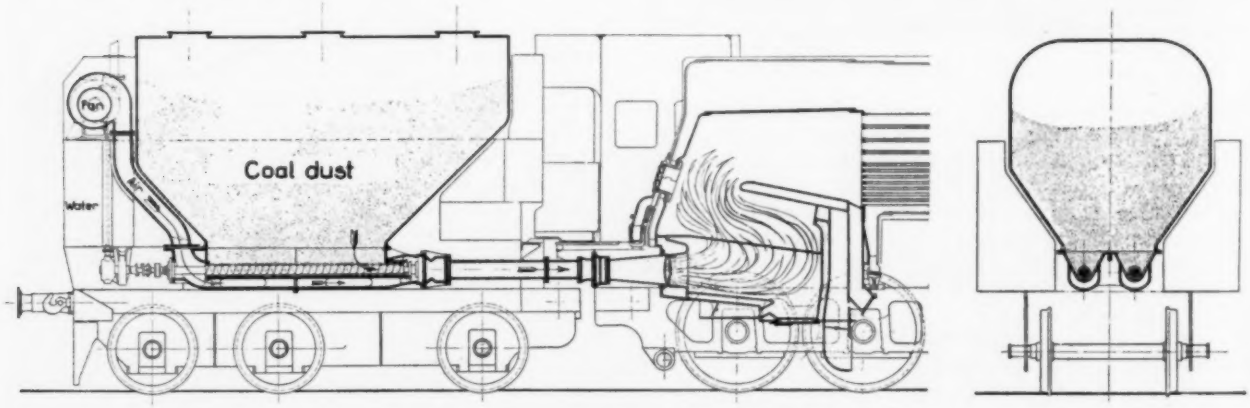


FIG. 9 LAYOUT OF STUG LOCOMOTIVE, LATEST DESIGN

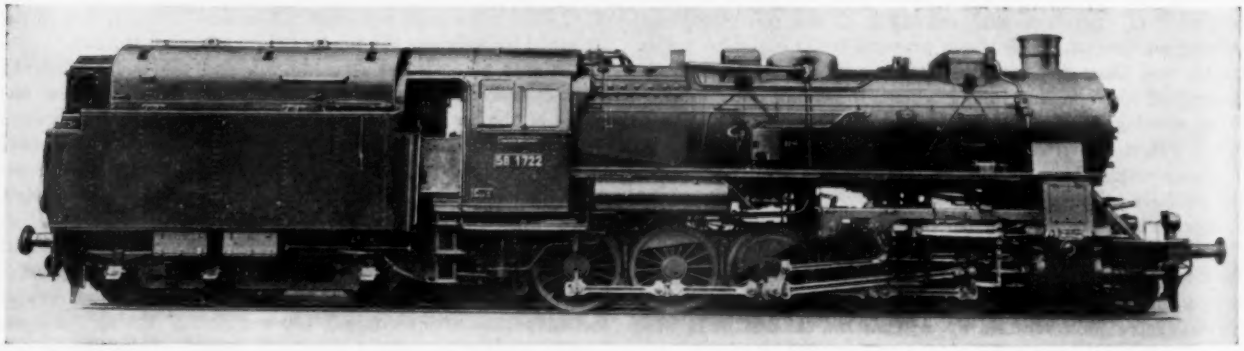


FIG. 10 SIDE VIEW OF STUG LOCOMOTIVE, LATEST DESIGN

In the course of these trials, which were made with a view to

TABLE 4 TESTS MADE IN THE MITTELFELD TESTING PLANT ON HARD COAL

	4-29-30	4-15-30	6-27-30	7-16-30	8-1-30	8-5-30	8-7-30
Date							
Kind of coal	Silesian coal		Ruhr coal				
Lower heating value, B.t.u. per lb	12184	12184	13605	13605	13618	13618	13618
Volatile constituents, per cent	29.9	29.9	21.1	21.1	20.08	20.08	20.08
Fuel consumed, lb. per hour	2482	3395	6305	1592	1951	2535	2954
Firebox stress, B.t.u. per cu. ft. per hour	1.42×10^6	1.94×10^6	0.402×10^6	1.01×10^6	1.25×10^6	1.62×10^6	1.89×10^6
Evaporation, lb. per hour	19941	26015	6601	14661	18129	22995	26191
Temperature of feedwater, deg. fahr	212	214	212	212	212	210	212
Coefficient of evaporation	8.04	7.66	10.45	9.22	9.29	9.08	.832
Evaporation of heating surface, lb. per sq. ft. per hour	9.59	12.52	3.18	7.05	8.73	11.07	12.6
Boiler pressure, lb. per sq. in.	193.4	193.4	192.0	197.7	197.7	197.7	196.2
Average temperature of superheated steam, deg. fahr	595	649	satd. steam	561	530	571	601
Average temperature of flue gas in smokebox, deg. fahr	583	651	435	523	529	564	577
Average CO_2 contents of flue gas, per cent	13.1	13.6	11.4	12.7	12.0	12.8	12.5
Temperature of primary air in burner, deg. fahr	173	172	183	176	170	164	161
Boiler efficiency based on a loss of heat of 12%, per cent	75.0	73.2	78.4	76.1	75.2	75.1	74.1

Free heating surface in firebox (not brick-lined), sq. ft	131.6
Heating surface in tubes, sq. ft	1945.1
Total heating surface, sq. ft	2076.7
Firebox capacity, cu. ft	211.9

$$\frac{\text{Freeheating surface in firebox (sq. ft.)}}{\text{total heating surface (sq. ft.)}} = \frac{131.6}{2076.7} = \frac{1}{15.8}$$

$$\frac{\text{Firebox capacity (cu. ft.)}}{\text{total heating surface (sq. ft.)}} = \frac{211.9}{2076.7} = \frac{1}{9.79}$$

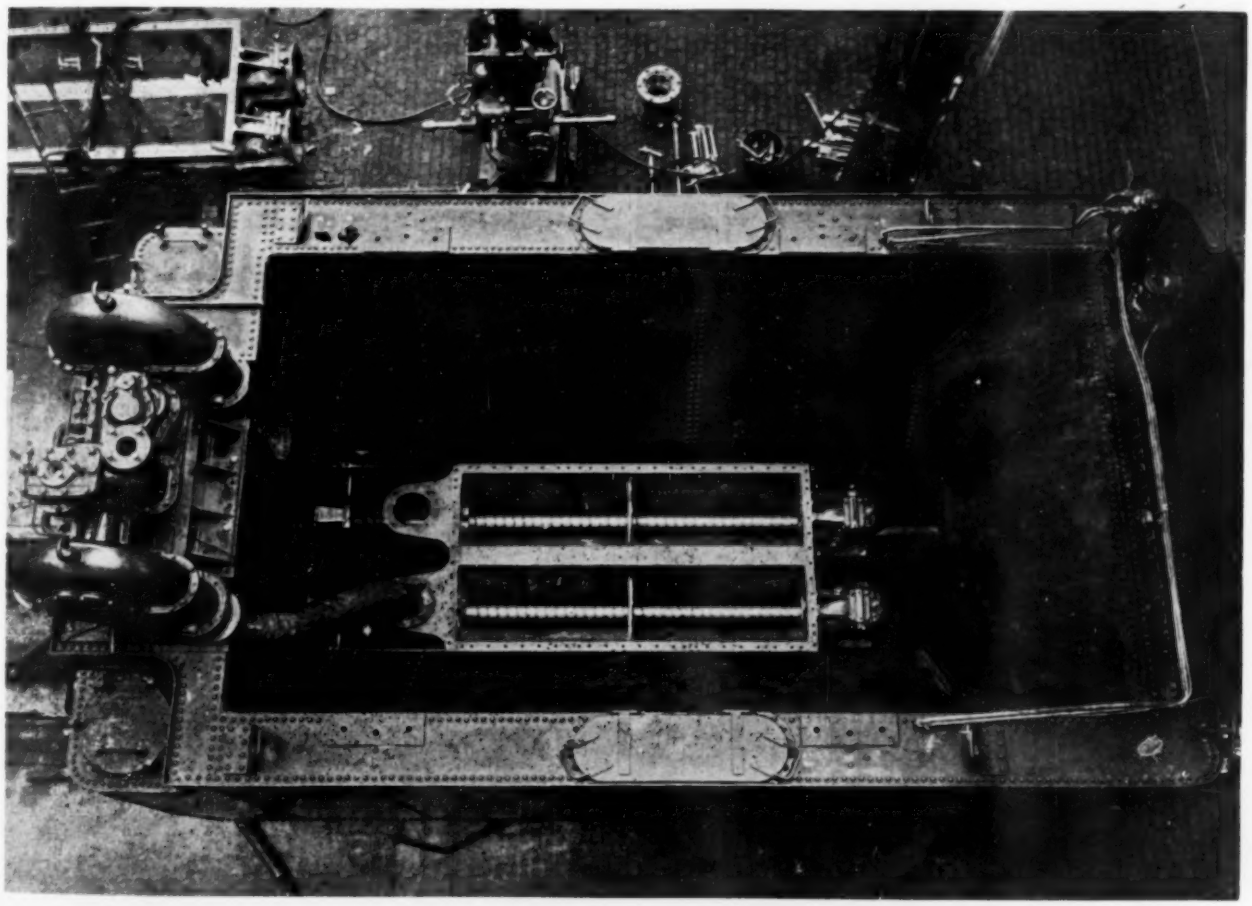


FIG. 11 WATER TANK, BLOWERS, AND DUST-BIN BOTTOM, LOOKING DOWN

obtaining greater simplicity, the behavior of the ash was given further attention. It is known that the larger part of the ash is carried away through the chimney, the remainder, however, remaining in the ashpan. A perfect pulverized-fuel firing system must avoid the formation of troublesome honeycombing on the tube sheet. This important problem, therefore, may be given more detailed consideration.

The tendency of the ash to form deposits depends on the temperature at which it will begin to soften and fuse. The combustion in the furnace, therefore, must be accelerated so that the ash will have cooled down below these temperatures before it hits the tube sheet. The temperature limit for this purpose lies between 900 and 1200 deg. cent. for most types of coal (Fig. 7). As it appeared from the tests, such acceleration is obtained by using dust ground to a sufficient degree of fineness, ensuring a perfect mixture of the dust and primary air, adequately timing the air supply to the firebox, a perfect mixture of the gases with the secondary air, and in the case of coal with little volatile constituents a certain preheating of the primary air by exhaust steam from the tender turbine. In this way

the Stug succeeded in avoiding honeycombing totally, or at least to such an extent that no trouble was experienced with it. It is noteworthy that these results were obtained in the very small firebox of the German State Railways' G-12 class engine in which a firebox stress of 235,000 B.t.u. per cu. ft. is produced with top loads. It is obvious that conditions must be more favorable with American engines having a larger firebox volume and very often a combustion chamber. With such designs, temperatures can be kept so low that the inconvenience of honeycombing is easily avoided. How good the results obtained by Stug were, will be seen from the photo (Fig. 8) showing the tube sheet after a peak-load performance on hard coal of several hours.

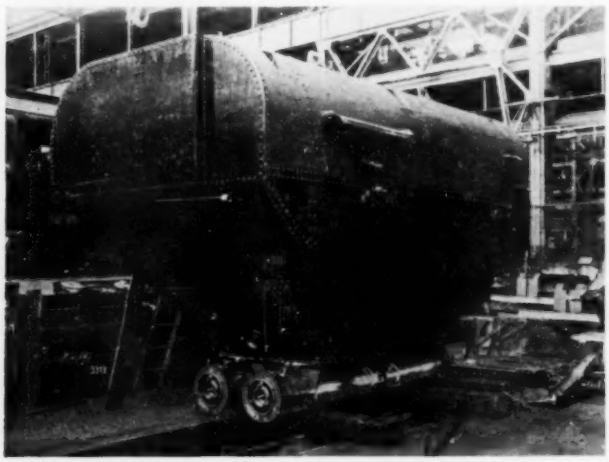


FIG. 12 DUST BIN

These investigations were instrumental in proving that hard coal and many types of foreign coal, such as Brazilian, Austrian, and Russian, which may be available for pulverized-fuel firing, can be fired to full advantage, the preceding Stug tests having demonstrated that the problem was solved in every respect so far as lignite dust was concerned. (See Table 4, referring to tests with hard coal.) In these hard-coal tests, the burner head was slightly modified where it joins the firebox, and the primary air was preheated to about 200 deg. fahr. by exhaust steam from the turbine. The hard coal used had no more than about 20 per cent of volatile constituents.

Similar results were obtained in burning dust from low-temperature lignite coke having only about 10 per cent volatile constituents.

As mentioned before, these tests, the purpose of which was the extension of pulverized-fuel firing to types of coal other than lignite, were carried out simultaneously with the trial runs of the first two lignite-dust-fired Stug locomotives on the German State Railways' lines. The experience collected by these further tests made at Kassel, and in particular the simplifications of equipment described, were of course taken advantage of in the construction of the further engines which were adapted for coal-dust firing by Henschel & Sohn on the German State Railways order, on the strength of the good results they had obtained with the two first ones.

These further State Railways' engines again were of the G-12 class, it being required to increase the bunker capacity of the tender while maintaining the original tender frame. This increase, from 6.4 to 11 tons, was achieved by suppressing the steam-motor and auxiliary-burner equipment. Fig. 9 shows the general layout of these engines and Fig. 10 the photo. The

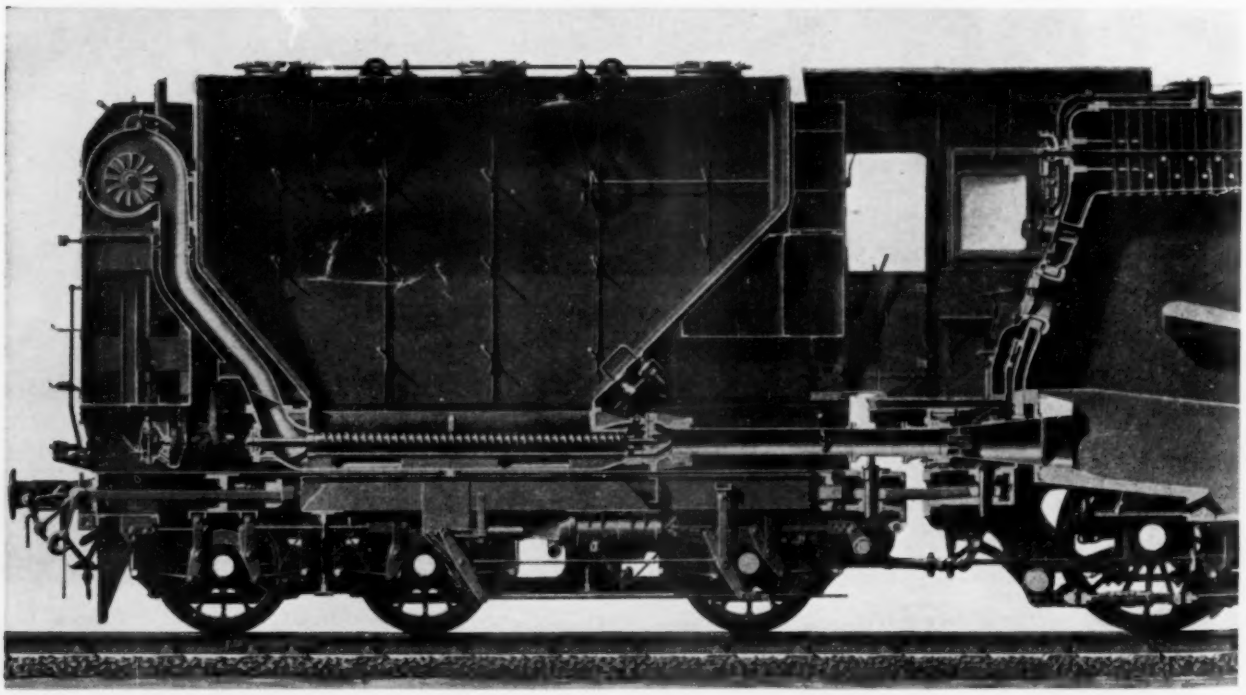


FIG. 14 LONGITUDINAL SECTION

water tank encloses the coal bunker in horseshoe fashion, as in the previous engines. The blowers supplying the primary air are arranged on top of the water tank at the rear end of the engine (Fig. 11). The blower casing is cast solid with the turbine casing, which ensures sturdy construction. The turbine shaft, by means of a worm gear, drives a vertical shaft extending

downward through the water tank, the latter shaft operating the two dust conveyor worms by a bevel and spur wheel gear. The gearing reduction is about 1 to 30, the conveyor worms rotating at a maximum of 150 r.p.m. The worms are located in two trough-shaped castings forming the bottom of the bunker and affording perfect alignment of the worm bearings (Fig. 12). The air current from the blowers encloses the trough in three-quarters of a circle and picks up the dust at the worm outlet, whence it is conveyed toward the burners through two pipe couplings with ball joints and stuffing boxes. The burners are again located below the firebox back plate. The ashpan casing is fitted with inlets for giving access to the secondary air. The size and number of these inlets depend on the type of coal used, one slot below the brick arch being quite sufficient for lignite. The brick arch extends inward to about one-half of the firebox length, thus producing an S-shaped flame. In order to remove such deposits as may form on the tube sheet owing to an occasional supply of inferior or too coarse-grained dust, an ash-blower is provided in the firebox back plate. It will be useful for cleaning the boiler in such cases and also can be operated on the run if necessary. Otherwise the engines have not been modified as against the conventional G-12 class, there being only the addition of a steam connection at the dome for the turbine on the tender. Of course, the blast pipe was adjusted so as to produce sufficient draft for drawing the secondary air supply into the firebox, a pressure of 4.2 lb. per sq. in. of the exhaust steam in the blast pipe deing the maximum required at top output.

The control of the engine is exceedingly simple. The fireman has but to regulate the supply of steam to the tender turbine by turning a single handwheel, thus varying the quantity of fuel and primary air. The ingress of secondary air is controlled by a valve in the ashpan. This clearly demonstrates the enormous relief to the fireman as against grate-fired engines. The dust conveyor worms are clutched and declutched by two ratchet levers conveniently arranged on the fireman's side. The air and dust supply systems are again so interlocked as to make them absolutely foolproof; i.e., it is impossible to start the conveyor worms without first producing an air current to carry the dust into the firebox (Fig. 13).

These engines, a general layout of which is given in Fig. 14,

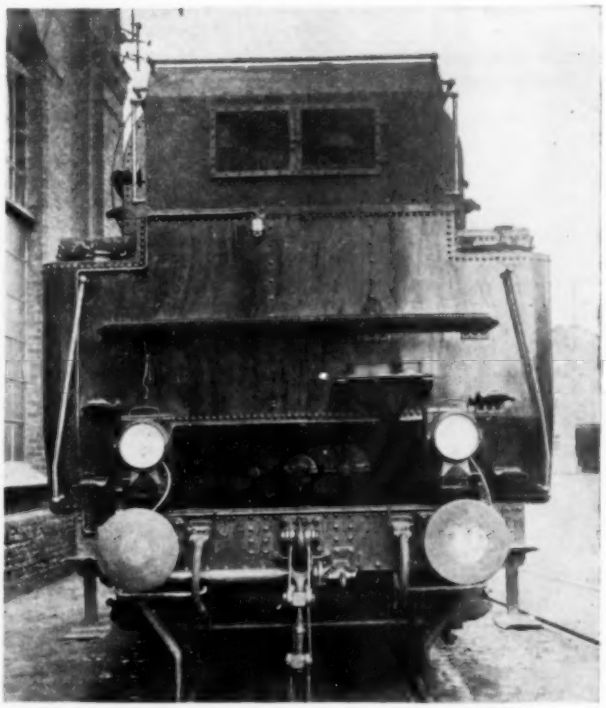
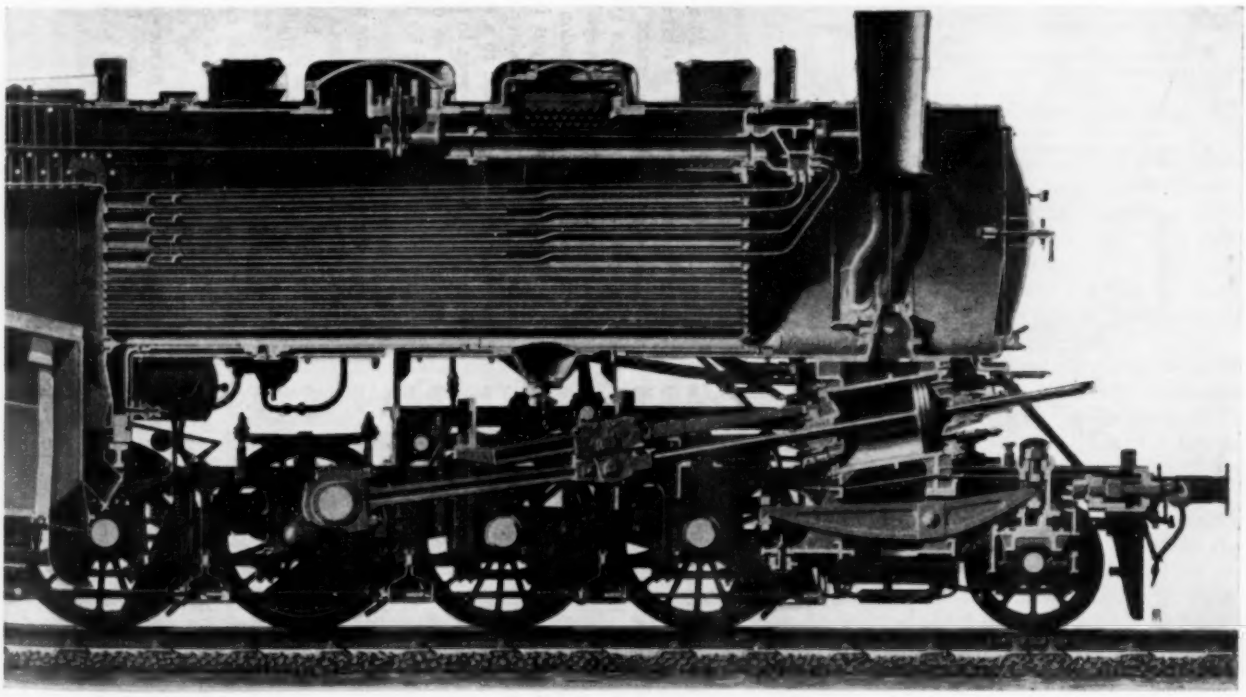


FIG. 13 REAR VIEW OF STUG ENGINE TENDER



OF NEW LOCOMOTIVE AND TENDER

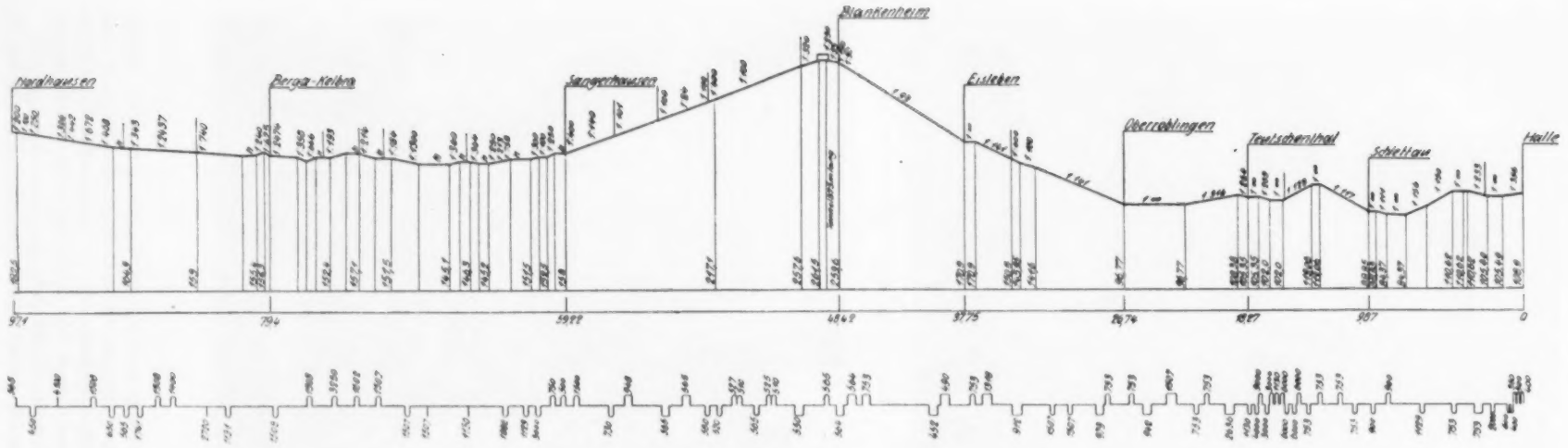


FIG. 15 PROFILE OF HALLE-NORDHAUSEN SECTION

were delivered to the German State Railways in the spring of 1930. After a few successful trial runs in the vicinity of Kassel, one of them was immediately assigned to the Halle district, where it has given excellent service ever since. The other engine was exhibited by the German State Railways at the occasion of the Second World Power Conference in Berlin. The visitors thus had an opportunity to closely view this engine, while the State Railways had arranged for them to participate in demonstration runs of one of the Stug pulverized-fuel-fired G-12 engines between Berlin and Magdeburg (about 100 miles). After the conference, the exhibit was turned over to the Grunewald Testing Department for thorough examination. The trial runs are now being carried out.

It will now be of interest to deal more explicitly with the coal-dust fired engines in actual service in the Halle district. These engines are running on various lines having long gradients and numerous curves (Fig. 15), hauling loads up to 1600 tons (the tractive weight being 81 tons).

Fig. 16 shows one of the various Stug engines on the road. During the last two years the engines were operated on dust coming from the separators of lignite briquet works in Central Germany. The dust can be used as it comes from the separators, no milling being necessary. It contains about 8 to 15 per cent ash, about 40 per cent volatile constituents, 10 to 15 per cent moisture, and has about 20 to 25 per cent residue on a 170-mesh screen. It is conveyed to the Halle locomotive depot, over a distance of 30 miles, in container cars owned by the lignite syndicates. From the container cars the dust is conveyed into the tender bin by compressed air, which operation takes about 15 minutes. The quantity of dust put into the tender is ascertained by weighing the container car on a track scale. The filling pipe is connected to a central opening on the tender bin fitted with a screen to retain foreign matter. Two further openings provide an outlet for the air and indicate the end of the filling by the small dust clouds rising from them.

The contents of the tender are generally sufficient for a round trip, more distant stations being at present supplied by container cars. It is, however, planned to install bunkers for refueling at Halle and some more distant points in the near future. The bunkers are so designed, as a result of thorough experiments conducted by Stug, as to ensure filling of the tender within a few minutes. Provision is made to obtain complete filling of the tender bin, which incidentally is also the case with the method now in use. For lignite-dust firing the stationary bunkers are to be supplied by railway-owned container cars, whereas for hard-coal-dust firing the bunkers are to be filled from mills erected on the site and working slack from the collieries.

Careful investigations have been made by Stug with a view to ascertaining whether it would be advisable to grind the fuel on the tender. The result, however, was that at present serious difficulties would be experienced in trying to design a mill to combine light weight, reduced volume, economy, and reliability to such an extent as would be required in view of the limited space on the tender and the considerable variation in locomotive output.

Further details from road experience will certainly be interestedly awaited.

It is noteworthy that during the whole running period there was not a single case of self-ignition or spontaneous combustion. There is, however, every reason to believe that, even if such an occurrence should come to pass in the tender bin, there would be no danger, as the glowing dust could be blown into the firebox.

Caking of the fuel in the tender bin was not experienced. In order to counteract arching of the dust, some upturned whirling nozzles in the sloping sides of the bin were provided. It was, however, hardly necessary to resort to them.

In lighting up a coal-dust-fired engine from cold, steam of 75 to 85 lb. per sq. in. pressure is taken either from a pipe line in the shed or from another engine under steam, the connection being made through the steam-heating pipes of the locomotive. This will start the tender turbine and set the blower ring on the exhaust pipe of the engine to work, the dust and fuel mixture

entering the firebox being ignited by a wood or cotton-waste fire. Once the steam pressure in the locomotive boiler has risen to about 80 lb., it will furnish the supply for further steam raising, and the outside source can be dispensed with. The time for thus steaming a pulverized-fuel burning engine is considerably shorter than in the case of a grate-fired locomotive.

It will be interesting to note that all of the auxiliary machines have acquitted themselves very well in nearly two years' road service. The conveyor screws were never clogged up. A fact deserving particular mention is that the holes in the burner plates were neither clogged nor worn by the impact of the dust and that the air cooling has been entirely sufficient as provided.



FIG. 16 STUG G-12 LOCOMOTIVE HAULING FREIGHT TRAIN

Experience with the brick lining was satisfactory, only little repair work being necessary.

While working safety was thus always on a very high level, it may yet be permitted to inquire as to what happens if one of the worms or burners fails. In this case the locomotive can be operated at reduced performance on the other burner. The risk in this respect is, however, no greater than that of the two boiler-feed devices of a locomotive failing simultaneously. How seldom this happens is well known.

Particular importance must of course be attached to the economical side. In the Halle district, the fact that pulverized-fuel-fired engines are running on an alternating schedule with grate-fired engines of the same class furnishes an excellent basis for comparison. The local conditions here are greatly in favor of pulverized-fuel firing, there being an abundance of lignite, whereas the principal hard-coal mining centers are about 250 miles away. Thus, lignite is not only basically cheaper, but also offers the advantage of considerably lower freight rates. This carries the cost of lump coal at Halle to about 28 reichsmark per ton, whereas lignite dust is 12 to 14 reichsmark delivered free onto the tender. The latter amount applies to lignite dust from separators, but mill dust can be had at the same price, in which about 3 reichsmark per ton for drying (raw lignite dust having 50 to 60 per cent moisture) and milling are included. This enables a large saving to be obtained in the fuel bill, as will be seen from Fig. 17. Curve *a* gives the amortization of a standard grate-fired engine over a period of 15 years; curve *b* showing that the dust-fired engine, in spite of a slightly higher prime cost, will pay in considerably less time, i.e., about 9.6 years, on account of the annual saving in its fuel bill. On the basis of equal life, therefore, the dust-fired engine will have produced a saving of $40,000, i.e., about its own value.

It thus appears that the use of pulverized-fuel-fired engines effects a considerable economy, which, with their reliability

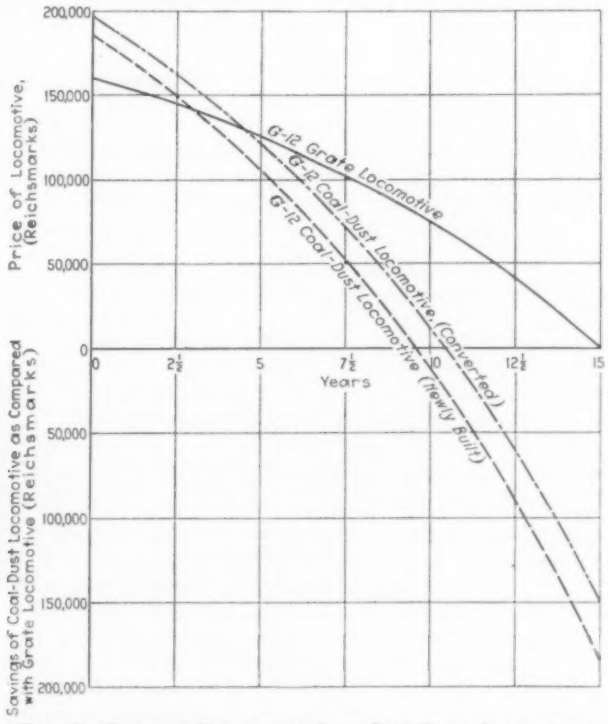


FIG. 17 ECONOMY DIAGRAM OF STUG G-12 CLASS LOCOMOTIVE

proved in actual service, strongly encourages its adoption on a large scale in the near future.

The Stug's research work has established that slack dust, too, has a bright outlook in Germany on account of the difference in price between lump coal and slack. This justifies a favorable forecast also in respect to engines fired with slack dust. This will be particularly appreciated for application to high-pressure locomotives, toward which there is a strong tendency, and which, on account of their small water spaces, make an easily adjustable fire control desirable.

Before closing this paper, some information should be given as to applications of the Stug system to stationary plants and ships. As was to be expected, the spray burner designed for heavy locomotive work has given good results in flue boilers, a boiler efficiency of 84 per cent having been obtained with lignite. The Stug system also has proved its applicability to hardening and melting furnaces. Very good results were obtained in cement and nitrate kilns, combustion being complete and economical in all these cases. Trials with marine boilers are now being carried out. A number of large stationary water-tube boilers were supplied by one of the members, the Hanomag concern.

It is a subject for investigation and discussion to consider the possibilities of the Stug system of pulverized-fuel firing in the United States. There is no doubt that its numerous advantages will go a long way in arousing interest conducive to its adoption.

Research Relating to the Action of 4-Wheel Freight-Car Trucks

By T. H. SYMINGTON,[1] BALTIMORE, MD.

This paper includes a study of operating and maintenance problems of car trucks that have resulted from increased weights, greater rigidity, and high speeds. The author discusses the 4-wheel truck as a whole, and includes such features of design as cross-equalization, swiveling resistance, self-squaring, car roll and nosing, guard-rail shocks, lateral motion, and four-point suspension.

Harmonic truck-spring action is discussed at considerable length. It is felt that excessive harmonic spring oscillation at critical train speeds may be caused by eccentricity of wheels. Tests will be made to determine this, and the author outlines various tests for determining unknown factors.



THE vital parts of freight cars are the trucks. We are using today the same fundamental principles in freight-car-truck design that have been in use for 75 years.

Modern heavy cars, some of great rigidity, operating at very high speeds, have brought with them many operating and maintenance problems. A scientific study of these problems and means for their solution are discussed in this paper.

There being no equipment in existence with which to make a proper study of the various problems involved, it was necessary to build two standard freight cars and equip them with much special apparatus of great exactness. Each car is also equipped with 12 water tanks to provide any desired load. The two cars were necessary in order continually to have a yardstick with which to compare the performance of different appliances. These cars are now very generally known and are shown in Fig. 1.

An accurate superimposed record is made on the recording table in car No. 1 of the following actions on each car:

1 Speed in miles per hour.
2 All car-body roll in relation to the constant plane of Sperry gyroscopes.
3 All truck-spring movements on both sides of the leading trucks.
4 All vertical movements of the center line of each car.
5 All lateral movements between the car body and one side frame.
6 All movements, at right angles to the journals, between the journal-box wedge and the roof of the journal box.

A telemeter record is made of the magnitude and frequency of all transverse forces and of the forces of vertical acceleration resulting from spring oscillation or end shock.

Each car is also equipped with an accurate spring dynamometer with which to measure the force of vertical acceleration resulting from end shock and a Kreuger-cell instrument with which to measure both the force of vertical acceleration resulting from end shock and the same maximum force of vertical acceleration resulting from spring oscillation.

Both cars are equipped with large periscopes through which to see and study all truck actions from inside the cars.

An idea of the accuracy of the equipment may be obtained from Fig. 1. Typical sections of the records obtained are shown in Appendix No. 2. Actually, the records of the performance of the two cars are made in different-colored inks. For easy reproduction, Appendix No. 2 was traced in full and dotted lines from actual records.

This research work naturally divides itself into four general headings, viz.: Safety, Damage to Lading, Train Resistance, and Maintenance Costs. These are all so interrelated that it is thought best to discuss the truck as a whole and then in detail.

The 4-Wheel Truck as a Whole

We have known for 50 years that, on any curve, there is always an essential sliding of three wheels on the rails. This cannot be avoided and constitutes the major part of constant-radius curving resistance.

Oiling the wheel flanges materially reduces this curving resistance, and also reduces rail wear on the gage side of the rail.

Nothing can be done to reduce the resistance and wear resulting from sliding between the treads of the wheels and the top of the rails.

Wheel sliding can be prevented only by having both axles always radial to the curve. This has never been accomplished in a simple, efficient 4-wheel truck design. The only truck yet produced where the axles are always radial to the curve is the Boyden six-wheel freight-car truck, discussed in Appendix No. 1.

This wheel sliding always necessitates, on any curve, a continuous high flange pressure against the rail of the outside leading wheel. No derailment on curves will result from this particular

[1] T. H. Symington & Son., Inc. Mr. Symington was born in Baltimore, Md., in 1869, and received his early education in the schools of that city. In 1887 he entered the Baltimore & Ohio Railroad shops, as machinist's apprentice, and served four years. He then went to Lehigh University, where he took a four-year course in two years, and received the degree of Mechanical Engineer. Following this he was with the Richmond Locomotive Works from 1893 to 1898, leaving there as assistant superintendent to become superintendent of motive power for the Atlantic Coast Line Railroad. In 1901 he organized the T. H. Symington Company and continued as its chief executive until the company was sold in 1925. During the war, he organized, owned, and operated six large companies in Rochester, N. Y., and Chicago, Ill., for the production of special machinery, ordnance, and artillery ammunition. Toward its close he was appointed Assistant Chief of Ordnance, in charge of the entire U. S. artillery ammunition program.

Mr. Symington originated and built the draft-gear test plant on which the United States Government made the first comprehensive draft-gear tests. He also originated and carried to completion research on cast-steel side frames that has resulted in the modern frame. Since 1925, he has been executive head of T. H. Symington & Son, Inc., and actively engaged in the research work covered by this paper.

Contributed by the Railroad Division and presented at the Annual Meeting, New York, N. Y., Dec. 1 to 5, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

flange pressure unless the weight on this wheel is unduly reduced.

Cross-Equalization. With flexible cars, the only cause of reduced weight on this leading outside wheel is excessive car roll that may put one-half of the entire body weight on one side bearing. With rigid-body cars and reduced side bearing clearance, track warp may also put the entire weight of one-half the car body on one side bearing 25 in. from the center. Only 15 per cent of the load is then on one side of the truck, and this sometimes is not sufficient to keep the wheel on this side from mounting the outside rail. With large side bearing clearance, excessive car roll also may result in derailments on approach curves, whether the car is flexible or rigid, because of insufficient cross-equalization of load and increased swiveling resistance resulting from excessive weight on one side bearing.

If the load on one truck never can be more than 16 in. from the center, the minimum proportion of the load on one side of the truck is about 30 per cent, which always is sufficient to keep a wheel from mounting the rail on curves from flange pressure.

Figs. 2 and 3 illustrate the two conditions—with and without cross-equalization. The desirability for increased cross-equalization of the load on all cars is obvious in the interest of safety.

When the load is so cross-equalized, there must be an auxiliary support at least 25 in. from the center in order to prevent any possibility of the car body rolling off the truck from centrifugal force when the car hits a curve at high speed.

Some truck designers have thought that equalization in line with the rail is desirable on 4-wheel trucks. Careful research has demonstrated that, while this equalization does no harm, it performs no desirable operating function.

A derailing condition results from warp in the track between truck centers and not from the warp between wheel centers on one truck. By "warp" is meant the amount that one point on the rails is out of the plane of the three other rectangular points on the rails.

The flexibility of the A.R.A. standard truck is always sufficient to permit one truck wheel to go down into a maximum-depth low

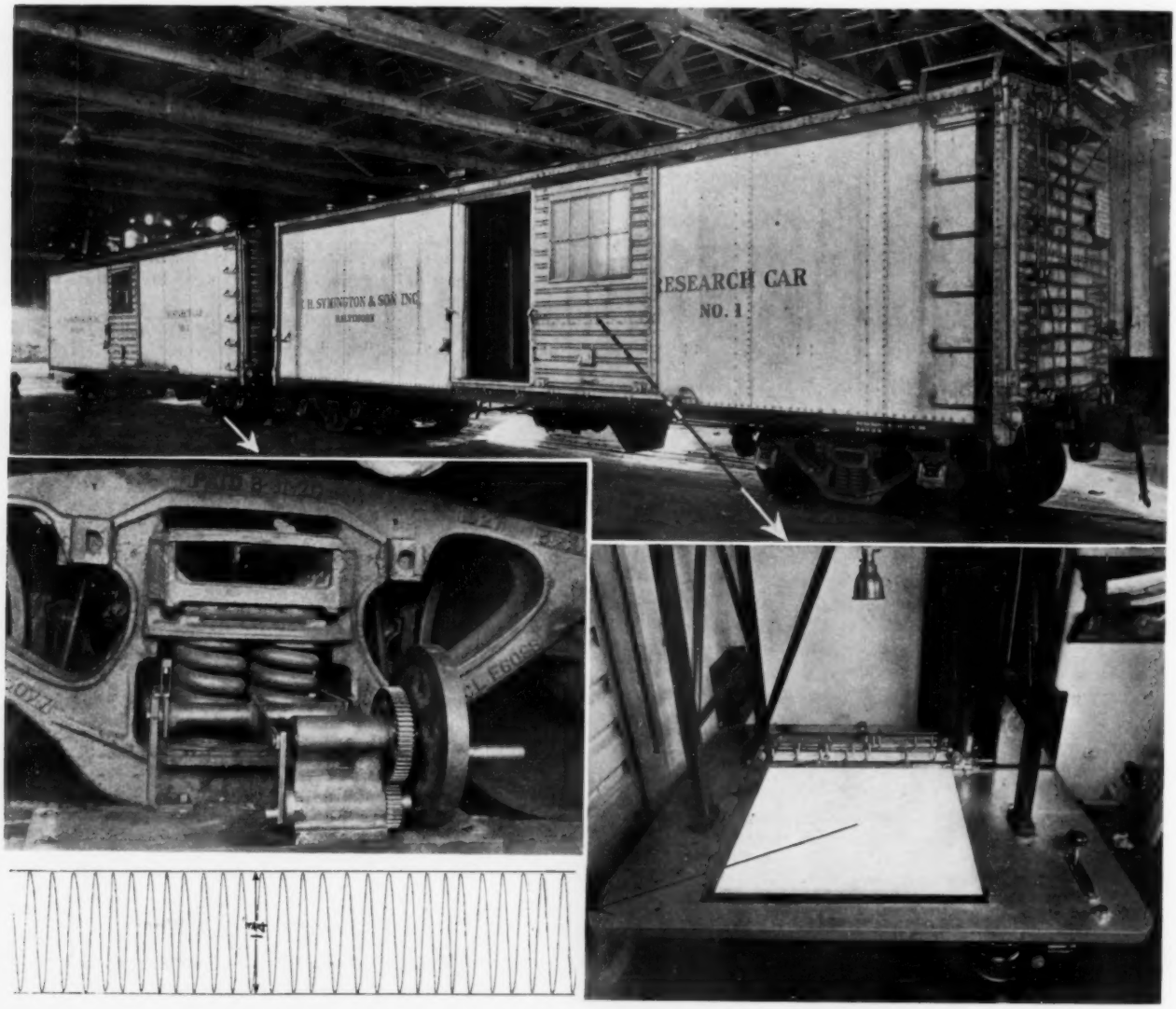


FIG. 1 CARS USED IN RESEARCH ON THE ACTION OF 4-WHEEL FREIGHT-CAR TRUCKS

(Crank throw at truck of Car No. 2 produced the equivalent of 1¾ in. of truck-spring movement. Diagram at bottom left was produced on recording table in Car No. 1 with 240 cycles of equivalent spring movement per minute. Paper roll moved by hand. Record showed exactly 1¾ in. of pen travel at this and all less number of cycles of movement per minute.)

TABLE 1 SWIVELING RESISTANCE. PRESSURE REQUIRED AT WHEEL FLANGE TO SWIVEL ONE A.R.A. STANDARD TRUCK OF A FULLY LOADED 55-TON BOX CAR WITH THE WEIGHT CONCENTRATED ON ONE SIDE BEARING

	Pressure, lb.
With friction side bearing	20,870
With roller side bearing	5,820
With T. H. Symington bolster	270

joint without losing its share of the load on this side of the truck.

Swiveling Resistance. There is no swiveling resistance between the trucks and the car body except on approach curves with changing radius. Table 1 gives the results of tests to determine the maximum swiveling resistance under various truck conditions, with the track warped 3 in. between truck centers to put excessive loads on one side bearing. It is realized that this excessively warped track is found only occasionally in industrial yards, but the identical swiveling resistance is often encountered on main-line approach curves when the car body has rolled over on to one side bearing.

Derailments. Most freight-car derailments occur when entering or leaving curves because, at these points on the line, the curve radius is changing and we have the combination of high flange pressure against the outside rail and minimum weight on the derailing wheel. On entering a curve, it is the rear truck that usually derails, and on leaving a curve, it is the leading truck that usually derails. The total flange pressure on approach curves is made up from:

a The pressure necessary to slide three truck wheels
b The pressure necessary to swivel the truck
c The lateral component of car-body roll.

When the car body rolls toward the outside rail, there is a maximum flange pressure because all three factors of pressure—*a*, *b*, and *c*—are involved. This pressure may spread the track, break the wheel flange or shear off the journal-box-brass lugs, but never causes a derailment because, with standard cars, 85 per cent of the body weight is then on this side of the truck.

When the car body rolls toward the inside rail, only factors of pressure *a* and *b* are involved, but the outside wheel will sometimes derail because then only 15 per cent of the body weight is on this side of the truck.

Table 2 gives the results of tests to determine the derailing tendency on approach curves with different trucks on warped track representing a soft spot at the outside rail, when the load was on the side bearing adjacent to the inner rail. Here, also, only factors of pressure *a* and *b* are involved.

Self-Squaring. It is obvious that, on tangents, minimum train resistance and flange wear result when the trucks are square and the flanges do not drag on the rails. Any design that will square a 4-wheel truck after coming out of a curve and keep it square is worth considering.

Any truck that will prevent the wheel flanges from exerting high pressure, first against one rail and then against the other, is worth considering, because both train resistance and flange wear are involved.

This surging results from either car roll or car nosing. If side-bearing clearance is large, cars are apt to roll excessively. If too small, cars with standard trucks will nose.

Observation and careful study of the action of the two research cars shown in Fig. 1, under varying speed, truck, and load conditions, lead to definite conclusions.

Car Roll and Nosing. Car roll results at certain speeds from a synchronous coordination of small rail-joint depressions, the inverted pendulum action of the car body, and the truck springs. Excessive car roll will sometimes result in lifting the wheels off the rails, first on one side of the truck and then on the other.

If the synchronous impulses from the rail joints are not sufficient to cause objectionable car roll, the truck will see-saw on its

TABLE 2 AMOUNT OF TRACK WARP BETWEEN TRUCK CENTERS RESULTING FROM A SOFT SPOT UNDER THE OUTSIDE RAIL ON A 10-DEG. CURVE CAUSING DERAILMENT OF A RIGID 55-TON BOX CAR WITH 18 TONS LOAD

	Side-bearing clearance, each side, inches	
	0	1/8
	Track warp, in.	
A.R.A. standard truck with A.R.A. standard bolster	1 9/32	2 3/16
A.R.A. standard truck with T. H. Symington bolster[1]	6	

[1] With this bolster there is no side-bearing clearance, and the truck will not derail until the body bolster comes in contact with the side frame.

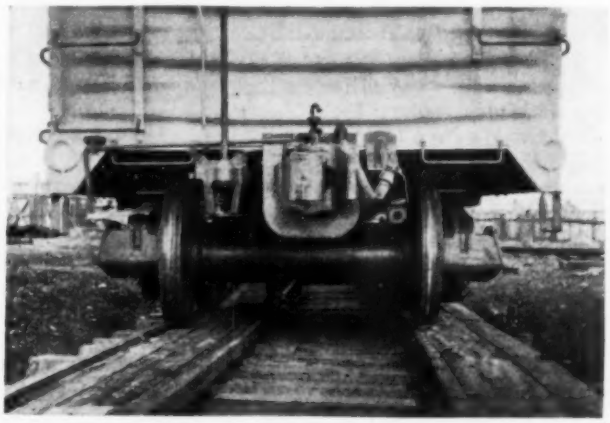


FIG. 2 A.R.A. STANDARD BOLSTER, 55-TON RIGID CAR, 18-TON LOAD. ROLLER SIDE BEARINGS, 1/8 IN. CLEARANCE EACH SIDE. A.R.A. TRUCK SPRINGS. CAR DERAILED

(The outside rail on this 10-deg. curve depressed to produce a track warp of 2 9/16 in. between truck centers when about 15 per cent of normal body load is on the outside truck wheels.)

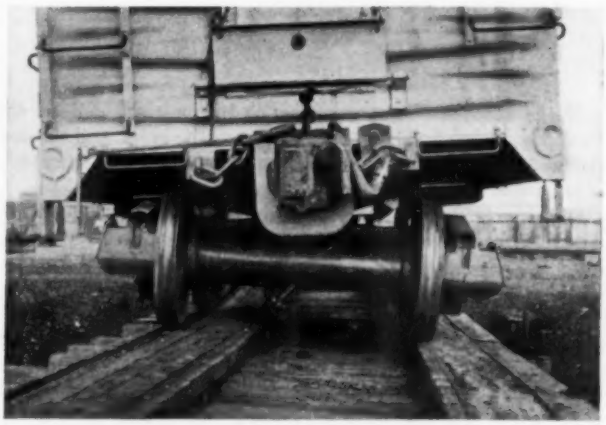


FIG. 3 T. H. SYMINGTON BOLSTER, 55-TON RIGID CAR, 18-TON LOAD. A.R.A. TRUCK SPRINGS. NO DERAILMENT

(The outside rail on this 10-deg. curve depressed to produce a track warp of 6 in. between truck centers when about 30 per cent of normal body load is on the outside truck wheels.)

center plate, when there is sufficient side-bearing clearance, and not disturb seriously the mass of the car body.

If side-bearing clearance is a minimum or at zero, these vertical rail-joint impulses directly affect the car body mass with resulting nosing.

This nosing originates from the car body. If side-bearing clearance is lacking, the truck cannot rock independently of the car body, and synchronous impulses from the rail joints will alternately compress the truck springs on opposite sides of the car. The lateral component of this action causes the car body to swing first to one side and then the other. This action occurs on all passenger cars. Without an easy lateral float of

the car body on the trucks, the lateral movement of the car body will cause the trucks to surge first against one rail and then against the other and result in rapid end wear on brasses and journals. This nosing has the same period as car roll, and can therefore be identified with the synchronous timing of the rail joints at certain definite train speeds, often about 17 miles per hour.

Car roll can be reduced by reducing side-bearing clearance and by increasing the stiffness of the truck springs.

Car nosing can be eliminated by increasing the side-bearing clearance or, with minimum side-bearing clearance, by providing a very soft, easy lateral motion.

Either construction will break up any objectionable synchronous nosing action of the car body and truck in tune with the rail joints.

Safety. We have taken adequate care to prevent accidents resulting from the trucks by providing ample strength in the side frames and bolsters and by providing safety supports for the brake beams. We have done nothing to the trucks to eliminate derailments and to solve the broken-wheel-flange problem. An analysis of these problems indicates the need for better cross-equalization to prevent derailments and an adequate lateral motion on all freight-car trucks to minimize lateral shocks.

Guard-Rail Shocks. Car roll, or car nosing, will often take up all lateral clearances between the car body and the collar of one journal. If, at this instant, the opposite wheel flange strikes a guard rail at speed, something must yield in the line of force from the blow at the guard rail to the body mass, namely:

1 The guard rail
2 The wheel flange
3 The journal collar
4 The stop lugs on the brass
5 The side frame
6 The bolster
7 The car body.

If the blow is taken by the opposite journal shoulder, the force must pass through the top flange on the brass, and through the wedge to the roof stop lugs on the box on the same side of the truck as the offending guard rail.

This is nothing but a force of lateral acceleration. The kinetic energy is proportional to MV^2, where M is the mass that is laterally accelerated and V is the velocity involved in this lateral acceleration.

If we consider the weight on the rails of one truck of a fully loaded 55-ton car as 100, the body weight on one truck is 90 and the truck weight is 10. With adequate lateral motion, the mass to be laterally accelerated at one instant is the truck only, or 10, and the velocity of the lateral acceleration of one wheel is in direct proportion to the speed of the train and the entering angle of the guard rail. If we consider that, for a certain speed and guard rail, this lateral wheel velocity is 2, the lateral velocity of the center of gravity of the truck mass is 1. Then MV^2 for the truck = 10.

With a similar car, without lateral motion, we must add the force to laterally accelerate one-half of the car body with load. In this case the body mass equals 90 and the lateral velocity is 1, because, at any one instant, this lateral velocity of one-half of the car body is one-half of the lateral velocity of the wheel striking the guard rail. Then MV^2 for the car body equals 90 and the sum of the two equals 100.

There are several factors of correction, namely: the lateral yield in the truck structure, the force needed to compress slightly the truck springs because of the small lifting angle of any lateral motion, and because the lateral force on the car body is applied at the center plate some distance below the center of gravity of the car body. We are certain, however, that the force of lateral acceleration at the guard rail without lateral motion is many times this force when we have adequate lateral motion.

The same advantages accrue from adequate lateral motion when the dynamic shock comes on the throat of the wheel flange.

If we can, with suitable lateral motion, greatly reduce this dynamic force, we automatically increase the factor of safety for the wheel flange many times and therefore largely eliminate broken wheel flanges.

If the wheel flange is strong enough to stand the shock, the brass is sometimes broken.

It would seem essential, therefore, that any lateral motion provide sufficient travel and gravity resistance so that there is *always* an ample reserve of yield to insure the minimum shock to the wheel flange.

It is fortunately a rather rare coincidence when a wheel flange strikes a guard rail at speed at the instant when all lateral clearances are absorbed in the opposite direction.

There is no doubt about the fact that there are many lateral shocks that are not sufficient to break a wheel flange or shear off the brass lugs, but are sufficient to break down the oil film on the journal collar, or shoulder, with resulting rapid end wear on brasses and journals.

Lateral Motion

An adequate lateral motion must accomplish two separate important functions:

1 The floating action at the center must be very easy in order to prevent nosing when side bearing clearance is at a minimum
2 There must be sufficient travel and gravity resistance to insure lateral yield under all operating conditions and to prevent the bolster from striking the side frame.

This subject can be studied best with the swing-hanger construction used on all passenger cars, which operate with little or no side-bearing clearance. These hangers vary in length from $28^1/_4$ in., spread $8^3/_4$ in. at the bottom, to the equivalent of $6^1/_2$ in. parallel hangers.

No matter what design is used, it is always a compromise to give the best results to eliminate nosing and provide sufficient yield and resistance.

With angular hangers, the bottom spread must be small to eliminate nosing and increased to give sufficient lateral resistance.

If parallel hangers are used, they must be long enough to eliminate nosing and short enough to provide sufficient resistance in the usual travel of $2^1/_4$ in.

It is good practice on a straight railroad to provide best against nosing, and on a crooked railroad to consider lateral resistance as of first importance.

Pullman cars that operate on all sorts of railroads probably offer the greatest difficulty in this compromise between nosing and needed resistance.

An ideal hanger for all passenger cars would seem to provide a compound lift curve to produce a very easy float at the center and ample lift toward the end of the motion.

Fig. 4 shows full-size lift curves:

(*a*) With the longest angular hangers in general service
(*b*) With the shortest angular hangers in general service
(*c*) With the shortest equivalent parallel hangers in service today
(*d*) With the Barber lateral motion, and
(*e*) An ideal lift curve that has no compromise.

Lift curve (*e*) can be produced either with compound swing hangers or with compression rockers.

It has been demonstrated that $6^1/_2$-in. parallel hangers will induce little nosing on passenger cars with no side-bearing clearance. The reason is that combined helical and elliptic springs have a very flat load curve, and therefore largely absorb the effect of track irregularities without disturbing the car body.

On freight cars, with only helical springs, track irregularities are more readily conveyed to the car body, and an easier lateral motion at the center than on passenger cars is required to prevent the car-body swing from carrying the trucks with it. Curve (*e*) has therefore been found best for freight cars.

One objection to all swing hangers is that the lateral motion is continuous and the millions of movements necessitate a periodic renewal of pins and bushings in the hangers on account of wear.

With properly designed rockers, there is no sliding friction and the parts will last, with no deterioration, for the life of the car.

When rockers, or rollers, are used for lateral motion, experience has shown that the car should be equally stable with the weight evenly distributed on the bolster, or concentrated on one rocker, which often occurs with rigid-body cars. This means that one rocker should give equal lift each way from central position. It is also important that the rocker-wear factor, viz., the product of its diameter by its length, be sufficient to insure long life with ordinary steel rocker bearings.

Four-Point Suspension. There has been much discussion about 3-point and 4-point suspensions. When cars are supported on 4 rockers, there is an even 4-point support only on level track with rigid-body cars. Often the rigid-body car is supported on 3 rockers, and, on unusual track, the main supports may be 2 diagonal rockers instead of 2 diagonal side bearings, as on standard cars.

Many attempts have been made in the past to carry a freight car on 4 rocker side bearings in order to minimize swiveling friction and reduce weight.

The only well-known cars of this construction in service are five hundred 100-ton coal cars on the Norfolk & Western Railroad. They were designed for great flexibility, as a rigid-body car of this construction would not stay on the rails because there is no cross-equalization of the load.

With rigid-body cars, the rocker supports must be sufficiently close together to provide the essential cross-equalization of weight necessary always to maintain 30 per cent of the body weight on the light-loaded wheels and thereby prevent derailments.

If the rockers are not of conical form, provision also must be made to take care of the angular movement between the truck and body bolsters, or the mechanism will lock and derail the truck on a curve.

The only reason for increased swiveling resistance with roller side bearings (see Table 1) when the weight is largely on one side bearing, is that the rollers are not of conical form, and therefore must slide a little on their bearings because of the angular movement between the bolsters.

When 4 rockers are used to support a car body, it would certainly seem desirable to arrange for gravity to square the truck when coming out of a curve. It is believed that this failure of the truck to square itself is responsible for increased train resistance and wheel-flange wear.

Barber Lateral Motion. The only lateral motion in general service on freight cars in this country is the well-known Barber lateral motion. This motion is the equivalent of parallel hangers $4^3/_8$ in. long. With such short hangers, cars will nose if there is little or no side-bearing clearance. The travel of $1^1/_8$ in., with a lift of $^3/_{16}$ in., may not provide sufficient travel and resistance always to insure lateral yield. The makers of this device advise that, if desired, they can increase the travel and lift, which would give better action to prevent nosing and to provide needed travel and resistance to avoid lateral shocks.

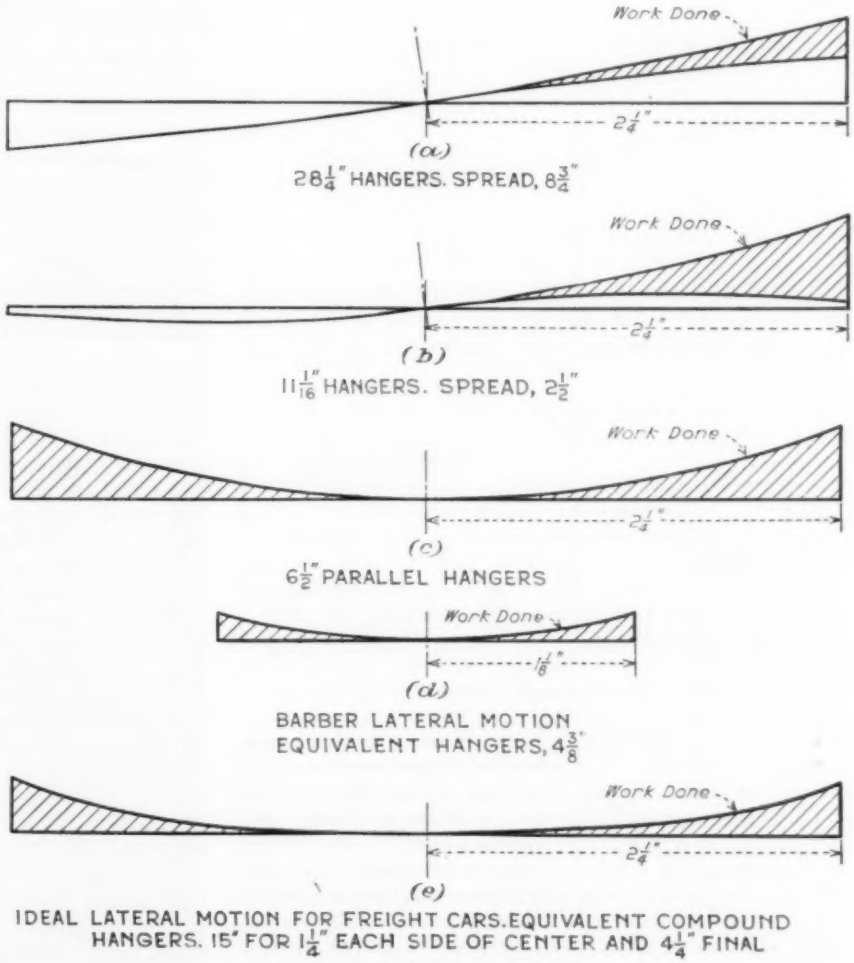


Fig. 4 Full-Size Lift Curves

(*a*) With the longest angular hangers in general service.
(*b*) With the shortest angular hangers in general service.
(*c*) With the shortest equivalent parallel hangers in general service.
(*d*) With the Barber lateral motion.
(*e*) An ideal lift curve that has no compromise.

The Truck Springs

With the large masses and high speeds of modern freight cars, the cumulative harmonic vibration of helical truck springs is responsible for a number of our operating problems.

Because of the small available space, freight-car truck springs

are made in helical or coiled form, and also because the same springs must be suitable for empty or fully loaded cars and there must be no excessive variation in coupler height.

Harmonic Spring Oscillation. All helical springs have definite periods of vibration dependent upon the springs themselves, the mass supported by them and the speed. This vibration, without pendulum action of the car body, is in tune with the intermittent forces from the rail joints in the track at speeds of from 35 to 60 miles per hour.

The resulting cumulative spring oscillation is probably the largest factor in damage to perishable freight and to truck springs. This oscillation is also a large factor in velocity train resistance and, in the author's opinion, for the initiation of transverse rail fissures when the springs go solid.

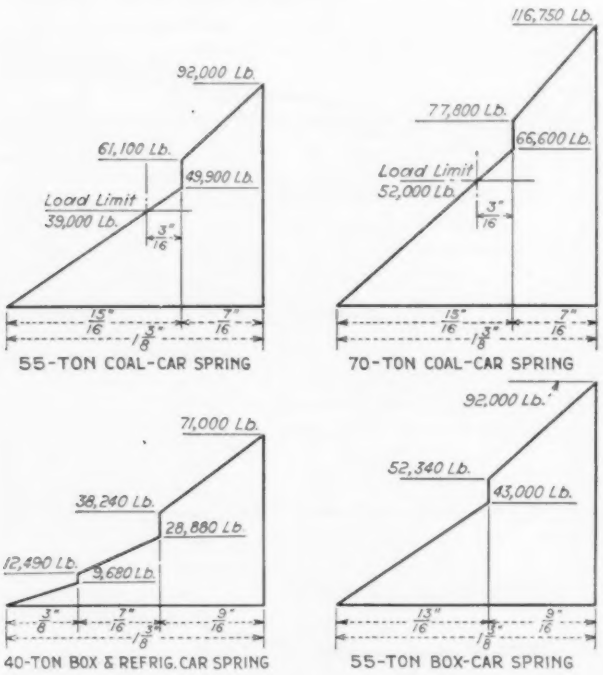


FIG. 5 NON-HARMONIC SPRING CURVES

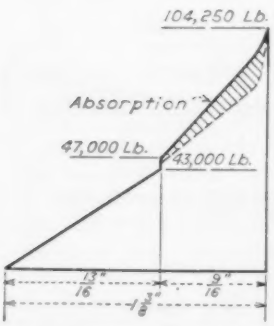


FIG. 6 SPRING CURVE OF 55-TON BOX-CAR SPRING WITH ONE SNUBBED EDGEWATER UNIT

We have frequently recorded spring oscillation that closes solid A.R.A. spring groups of 40 and 55 tons capacity at the rate of 3 to 4 times per second.

All cars are subject to spring oscillation at certain particular speeds. We often identify one type of car as jumping when other cars are not jumping. This is because the critical speed for the other cars was not attained during the time of our observation.

Few railroad men realize that the shock inside a freight car from spring oscillation may cause a man to crash through an ordinary chair to the floor of the car. When once experienced, one can easily understand why so much beef is found on the floors of refrigerator cars; why fat cattle lose from 10 to 15 per cent in weight in a long shipment to the stockyards; why certain fruits must be picked so green, in order to stand shipment, that they never reach perfection at a distant market; why we have so many spring failures on cars loaded to the rail limit; why such loaded cars do so much damage to rails.

The breaking up of harmonic truck-spring action will automatically solve all of the above problems.

The first moves to stop the failures of truck springs under harmonic action were to increase the static capacity of the coils and then to add more A.R.A. standard coils and increase the static capacity of the spring group. Both actions materially helped to diminish spring failures, but had no effect in reducing harmonic spring action, except to increase the critical speed for this action. All such heavier-capacity groups will go solid under harmonic action when the track, the lading, and the train speeds are favorable to such action.

Concentrated effort is now being made by many railroads to break up this harmonic truck-spring action by the use of various means to introduce friction in the spring action so that the compression curve of the spring will vary materially from the release curve.

Excessive harmonic truck-spring action can be prevented by constructing spring nests that have irregular compression curves as illustrated in Fig. 5.

The best general performance of springs was had with a spring group having the curve represented in Fig. 6. In this spring group, an Edgewater ring spring was under sufficient initial compression so that it was inoperative except under harmonic spring action. It is evident that any harmonic action tends to be broken up both by the sudden change of direction in the combined spring curve and by work absorption.

A great advantage in this spring-group construction is that the friction elements are only working in an emergency, and can therefore be relied upon for a long life.

It is believed that a snubbed Frost spring in the same group would give approximately the same results.

The first essential for any truck spring would seem to be to prevent its ever going solid under vertical oscillation. The fiber stress then, at some point in a coil, might easily go to 250,000 lb. per sq. in., when there would be a certain failure.

If one coil in a nest is broken, the spring group will thereafter go solid much more readily, with resulting destructive shocks to lading and to the rails.

It is believed by many engineers that excessive harmonic spring oscillation at critical train speeds may be caused by eccentricity of the wheels. Tests will be made to determine what, if any, reduction in harmonic spring oscillation can be effected with wheel treads ground concentric with the journals.

Some efficient and durable means will certainly be found to break up this destructive harmonic spring action, and it is believed that the subject can be studied scientifically in the simplest way with the two research cars for which the author is responsible. These cars being identical, the action of any two types of spring can be recorded accurately and compared under identical service conditions. It is of course necessary to record the action of any type of spring at all speeds up to, say, 60 miles per hour, and with, say, one-quarter, one-half, three-quarters, and full lading.

MEASURING THE FORCE OF VERTICAL ACCELERATION

Fig. 7 shows the spring dynamometer and Kreuger-cell instrument installed at Station A in each car to measure the force of vertical acceleration resulting from the vertical component of end shock. The dynamometer instrument is of 1000 lb. capacity and the suspended weight is 50 lb.

We know that the actual force of vertical acceleration is greater than the dynamometer indicates because of the slight

yield in the spring, but the readings in the two cars are entirely comparable.

These dynamometer instruments can be depended upon only when subjected to a single force of acceleration, and will not properly measure forces of acceleration of high frequency such as result from spring oscillations.

They have been successfully used to record the force of vertical acceleration resulting from end shock.

A 55-ton loaded coal car was drifted into Car No. 1, which was backed up against a string of cars and brakes set on Car No. 2. Readings were taken at five points in Car No. 1, as shown in Fig. 8, and compared with the reading of the fixed instrument at *A*.

It will be noted that, in this car, with this type of loading, the highest recorded force of vertical acceleration was at Station 2. At 3 miles per hour, the dynamometer at Station 2 recorded 1000 lb.

Tests were then made with one horizontal dynamometer in-

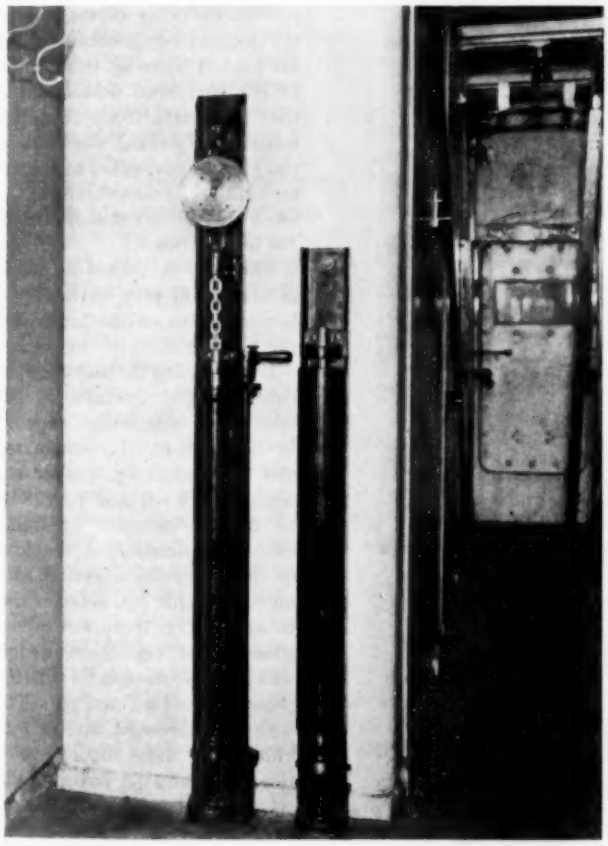


FIG. 7 SPRING DYNAMOMETER AND KREUGER-CELL INSTRUMENT INSTALLED AT STATION A IN EACH OF THE CARS SHOWN IN FIG. 1

strument fastened to the car floor at Station 2, opposite the vertical instrument at Station A, and the recorded force of vertical acceleration at Station A was from 5 to 6 times the force of longitudinal acceleration at Station 2, dependent on the speed of impact. Table 3 gives the results of three impacts.

It is believed that, for all brittle ladings, end shock is far more destructive than spring jump. These high forces of vertical acceleration are dependent on the efficiency of the draft gear.

It would help materially to provide yield between the lading and the car body which would function like the spring-cushion seat in an automobile.

TABLE 3 COMPARATIVE FORCES OF HORIZONTAL AND VERTICAL ACCELERATION RESULTING FROM END SHOCK

(Comparative readings taken with two identical spring dynamometers.)

	Horizontal	Vertical
First shock	150	970
Second shock	180	840
Third shock	90	400

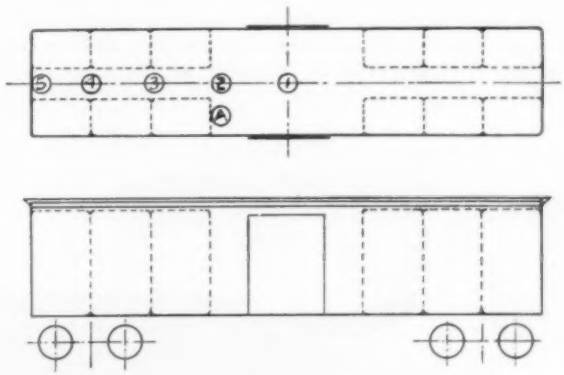


FIG. 8 LOCATIONS OF DYNAMOMETERS IN RESEARCH CAR IN END-SHOCK TESTS. LOAD IN CAR, 18 TONS

[One dynamometer permanently located at *A*. For end-shock tests an identical dynamometer was placed at points (1) to (5). Readings compared between the two instruments for each end shock gave the following percentages: *A* = 1.00; (1) = 0.28; (2) = 1.00; (3) = 0.765; (4) = 0.104; (5) = 0.071. For comparison of longitudinal and vertical acceleration the extra instrument was placed in horizontal position at (2).]

It is probable that excessive spring oscillation at the rate of 3 to 4 times per second is responsible for the shaking down of perishable fruits and vegetables.

The Kreuger-Cell Instrument. This instrument, named after its inventor, a Swedish professor, is considered by our Bureau of Standards as equal to the telemeter in accuracy for measuring dynamic forces. It will, however, only measure the maximum applied force.

With this instrument, the compression, within its elastic limit, of a section of a ball is measured. The radius of the ball is 10 in., which is suitable for this range of pressures. The ball's surface is in contact with a piece of flat hardened steel, ground and polished. The flat surface is covered with a very thin coating of camphor smoke, and any applied force will produce a definite circular impression in the smoke. The diameter of this circle is then measured with a microscope, the instrument having been previously calibrated in a static testing machine. This instrument is far more dependable for recording impact pressures than any Brinell instrument, and is entirely suitable to check the accelerometer record of maximum forces of vertical acceleration resulting either from end shock or from spring oscillation.

The Telemeter. This instrument, in the present application, operates as follows: The force to be measured passes through a piece of chrome-vanadium steel, properly heat treated, which force must not exceed the elastic limit of the section. Within this piece of steel, and subject to the same elastic compression under load, there is placed a highly refined carbon pile, the electric resistance of which varies directly with the pressure on the pile. This changing electric current produces an unbalance in a Wheatstone-bridge circuit that is exactly proportional to the pressure on the pile. The unbalance in the Wheatstone bridge causes the twisting of a pair of tungsten wires. On these wires there is a tiny mirror. This mirror reflects a beam of light upon a moving photographic film. After the instrument is calibrated, this record of force is very accurate.

The recording instrument is called an oscillograph. For this particular work, where the oscillograph is placed in a vibrating freight car, it had to be redesigned as follows:

1 The tungsten element is shortened from 4 in. to 2 in.
2 The tungsten element, with mirror attached, is immersed in oil to eliminate any vibratory action of the mirror.
3 The oscillograph is supported in all directions on sponge rubber.

In connection with the telemeter in this installation, an accelerometer is placed over the rear truck in each car for measuring the forces of vertical acceleration resulting from spring oscillation. The accelerometer operates on the same principle as the telemeter, and a record of the vertical acceleration in each car is made on the moving photographic film in the oscillograph in Car No. 1.

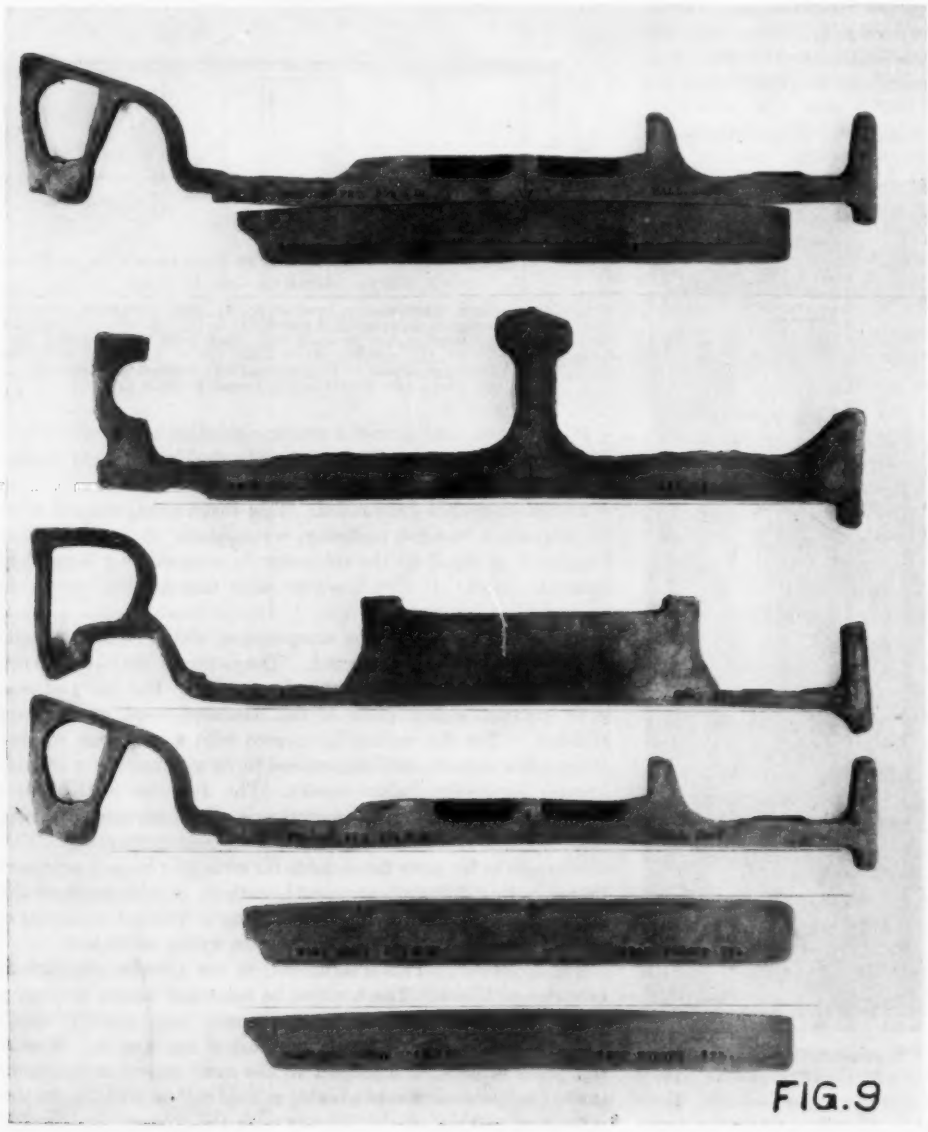


FIG. 9 WEAR BETWEEN TOP OF JOURNAL-BOX WEDGE AND ROOF OF JOURNAL BOX

THE JOURNAL-BOX WEDGE

A number of railroads are having difficulty with the wear between the top of the journal-box wedge and the roof of the journal box. If the wedge is harder than the box, the wear occurs in the roof of the box. If the box is harder than the wedge, the 78-in. radius on top of the wedge is worn flat. Fig. 9 shows a photograph of actual conditions as they exist.

This is a very serious matter, because, with loss of proper equalization on top of the wedge, there may result an excessive load at the front or back end of the journal that will cause a hot box.

Journal bearings often wear tapered, and if this tapered wear is coincident with loss of equalization on the wedge, a new brass will certainly have a concentrated load near the shoulder or the collar of that journal. A study of this matter on the research cars has established the fact that all of this wear, resulting in loss of equalization, is caused by the wedge's sliding on the roof of the box at right angles to the journal.

It has been demonstrated that all journal brasses are normally against the outer center lugs in the journal boxes because they are pushed there by the brakes. It has also been demonstrated that there is a frequent movement of the journal and brass in the journal box, often to the extent of the clearance between the brass and the center stop lugs in the journal box.

This play is always in excess of the lateral play between the beveled faces of the brass and the beveled faces of the wedge.

By increasing the play between these beveled surfaces, it has been found that wedge slippage in the box is entirely eliminated and the radius on top of the wedge can be reduced from 78 in. to 24 in., thereby providing better equalization of the load on the center of the journal, with no loss of this equalization due to wear. Fig. 10 shows the construction of this new wedge, which is interchangeable with the present standard wedge. The wedge is hardened and is provided with three small beveled tits that gradually imbed themselves into the roof of the journal box.

One blow from the journal shoulder drives this wedge against the front roof stop lugs in the journal box, and thereafter it never shifts in the box. There is ample bearing surface to permit, without wear, transverse sliding and sliding in line with the journal between the flat bottom of the wedge and the flat top of the brass. It will be noted that provision is made to prevent any possibility of the standard brass upsetting in the journal box should there be a seizure between the brass and the journal.

SPRING PLANKS

A study of the action of the A.R.A. spring plank on standard

trucks has led to the theoretical conclusion that it performs no important function. The function of the spring plank is to hold the truck square; that is, to keep one side of the truck from getting ahead of the other. An exhaustive investigation of the actual fits of the four bosses of the A.R.A. side frame in the four holes in the spring plank has shown the manufacturing necessity for sloppy fits, which permit an initial large angular movement between the side frame and the spring plank. It is believed that if the bearings between the side frames and bolster are sufficiently long and close fitting, the bolster can be utilized to maintain essential squareness of the truck. The spring plank can then be dispensed with entirely and the truck weight thereby reduced about 600 lb. on each 70-ton car. When the spring plank is eliminated, it is a simple matter to arrange the truck so that the cost of changing wheels is largely reduced.

It is not considered sound from a purely engineering angle to tie the side frames together at the bottom to a fixed dimension when the tops of the side frames are not similarly controlled.

The bolster applies all lateral forces to the side frames, and, without a spring plank, we are certain that the reaction points are at the tops of the journals. Secondary lateral stresses in the side frames are thereby minimized.

Service tests are in progress to demonstrate the efficiency of this type of truck construction.

Side Frames and Bolsters

Cast-steel side frames and bolsters have been vastly improved in design in the past few years. Further improvement can be made. The ideal ultimate standards will have essential strength, minimum weight, and maximum wearing surfaces to insure long service life.

This will be accomplished by designs that minimize secondary stresses and prevent a concentration of such stresses at any points in the structure. Metal that is never adequately working also should be eliminated. It is believed that future specifications for these parts will be based largely on elastic limits.

There are today a very large number of designs in current use that are not interchangeable and require a multitude of patterns and coreboxes. Brake-hanger brackets are also of various designs and degrees of efficiency and ultimately will be standardized.

Manufacturing tolerances permit quite a difference in the lengths of side frames, and the practice will soon become general of mating side frames in the same truck as now holds in mating wheels on the same axle.

As the normal position of each brass is against the outer center stop lug in the box, it would seem proper to mate side frames on the basis of the distance between the faces of the outer center stop lugs and not from center to center of journal boxes.

Additional Research

When the writing of this paper was undertaken, it was believed that this entire research could be completed in time to tabulate all the results. Unforeseen delays have made this impossible.

It is considered premature to comment on truck-spring performance at this time. We first must get the record of performance of all types of truck springs at all speeds up to 60 miles per hour and with various ladings.

No tests have yet been made to measure the magnitude and frequency of lateral forces or of the effect of vertical spring oscillation on perishable freight.

An exhaustive program for joint freight-car-truck research has, at this writing, October 1, been arranged between several of the larger manufacturers of trucks and springs and one of our important railroads. The results of this work cannot be included in this paper, but will, at a later date, be made public.

Appendix No. 1

THE BOYDEN TRUCK

The Boyden 6-wheel freight car truck is a splendid example of how *not* to introduce a new device on a railroad. It was prematurely put in service.

One 120-ton car on the Virginian Railroad was equipped with Boyden 6-wheel trucks many years ago. On the first run, improper weight distribution and excessive car-body roll caused a truck to derail and the car turned over. The truck was then redesigned by a competent truck engineer to distribute better the load on the wheels, and essential stops were provided to limit the body roll. As far as possible, old patterns were used and no refinement of design for reducing weight was made. This car has since been in continual successful operation for five years and has made about 75,000 miles with the original steel wheels that have never been out from under the car.



Fig. 10 Showing Construction of New Wedge Which Is Interchangeable With Present Standard Wedge

This truck was built without regard to weight and is too heavy. Any good truck designer can bring the weight down in line with other 6-wheel trucks.

It is believed that, with 100 cars equipped with this truck in refined form to eliminate superfluous weight, a dynamometer car would show a very large reduction in train resistance. This, coupled with a much longer average life for steel wheels and rails, might easily result in the economic replacement of other 6-wheel trucks now in service.

The Boyden principle can easily be adapted to 6-wheel passenger-car or locomotive-tender trucks with equally satisfactory results.

* * *

In presenting his paper the author said that when a loaded high-gravity car with any existing trucks rolled excessively on an approach curve, nothing could insure against a derailment. It had been proved that car roll could now be eliminated.

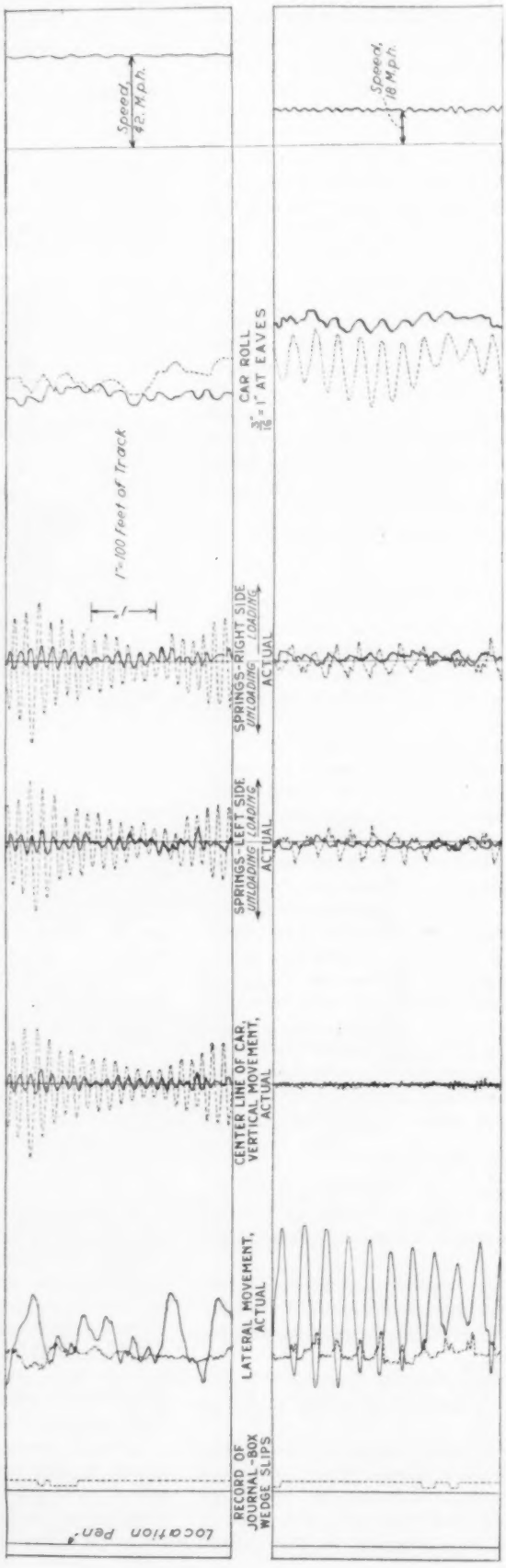
When a rigid body car with any existing trucks and with small side bearing clearance encountered a soft spot on an approach curve, nothing could insure against a derailment. It had been proved that freight-car trucks could now be made safe on curves with a run-off of $1^1/_2$ in. in 10 ft.

Harmonic spring action on loaded cars, with any coiled truck springs, at their critical train speed sometimes resulted in the springs going solid at the rate of 3 to 4 times per second, and these hammer blows on the rail, in the author's opinion, initiated transverse rail fissures. It had been proved that harmonic truck-

Appendix No. 2

SPECIMENS OF RESEARCH-CAR RECORD WITH 40-TON SPRINGS IN EACH CAR. SPRING-NEST LOAD, 17,350 LB.

Full Lines: Car No. 1 with non-harmonic springs (Fig. 5), full lateral motion [Curve (*e*), Fig. 4], and non-slip journal-box wedges.
Broken Lines: Car No. 2 with A.R.A. springs, no lateral motion, and standard journal-box wedges. Records reduced in size for publication. Original length, 23⅞ in.



spring action could now be broken up so that the springs would never go solid.

All the evidence indicated that damage to perishable freight could be largely reduced by the use of non-harmonic truck springs.

The lateral forces with standard trucks were sometimes responsible for spread track and usually responsible for broken wheel flanges. It had been proved that the magnitude of these lateral forces could now be reduced many times.

All the evidence indicated that train resistance could be largely reduced with perfected trucks that would minimize friction, oscillation, and concussion. The dynamometer car alone would establish this fact.

All the evidence indicated that maintenance costs on track, wheels and axles, all truck parts and car roofs and framing could be largely reduced with perfected trucks. Time alone would definitely establish this fact. Any improved truck must be so designed as to insure a very long life.

Some railroads figured that it costs 5 cents per pound per year to pull around excess dead weight. Then 500 pounds surplus weight was $25 per car per annum.

Research of this character must, of necessity, be undertaken by private interests. It would receive railroad endorsement only if it was scientifically sound and if its purpose clearly led to definite economic advancement.

While those present might not agree with the conclusions so far reached in this truck research, he was confident that they would have difficulty in finding fault with the methods employed to establish the facts in connection with the very intricate and vital mechanical problems involved.

Discussion

F. H. Clark.[2] The paper does not give details of the author's truck, but the writer assumes that the present-day center plates disappear and that the car body will be carried on rockers placed between the body and truck bolsters.

The author presents what amounts to a protest against the inaccurate construction that has always prevailed in this country in assembling freight-car trucks. He mentions three points; first, the spring plant connections to the side frames—and the writer is inclined to agree with him that the spring plank might well be dispensed with. The best spring plank that the writer ever saw was one which had no rigid connection to the side frames. The suggestion that side frames be mated for length is one that also meets with the writer's approval.

As to journal boxes and contained parts, the only improvements made in over forty years that the writer now recalls are in the substitution of malleable iron or cast steel for cast iron in the box itself and the application of close-fitting lids.

The journal bearing and wedges and the roof of the box against which the wedge bears are still rough and loosely placed, which may in a way be an advantage when we consider the fact that side frames are not mated and that the spring plank may put the truck permanently out of square instead of squaring it as intended.

These are all matters of detail and might apply to any truck. As to the relation of the truck to the track, the reduced wear of wheels and rails on curves and the lessening of derailments are important points and it looks as though much might be done in this direction.

F. J. Herter.[3] The method of supporting the car body used in the Symington bolster is apparently unique, in that it reduces swiveling resistance, so that it becomes practically negligible as is shown in Table 1. This should reduce train resistance to a large extent on curves at points where the radius changes.

It seems that the function of the rocker to prevent derailment does not have much advantage over other types of side bearings, provided that the other types are placed the same distance from the center of the car with the added protection of a support outside of the side bearing to keep the car from overturning under severe conditions. However, there is one decided advantage in the use of this bolster—no side-bearing clearance exists to permit the car body to attain a large initial velocity laterally to produce car roll. The function of the rocker to provide lateral motion is very effective in reducing high stresses due to shocks resulting from flange impact with rails, including guard rails. In summing up all the advantage of the Symington bolster, it must be admitted that it accomplishes much to be desired.

It might be questioned whether or not the car body would overturn on the rocker in the event something should lodge on the rocker seat and restrict the rocker action. This would, in effect, be the same as placing a rigid side bearing much nearer the center of car.

The discussion on truck springs brings out the necessity of overcoming excessive spring oscillations. It has been said that the oscillation of springs under stock cars has broken the legs of hogs. This does not seem unreasonable in view of the statement made in the paper that the shock inside of a freight car from spring oscillation may cause a man to crash through an ordinary chair.

From the experiments made by the use of the spring dynamometer to determine vertical acceleration due to end shock, it may be found that this is much more serious as it affects lading than spring oscillations, and should be overcome, if possible. The author refers to this vertical acceleration as the result of the vertical component of end shock. It seems to the writer that it might be better to say that the vertical acceleration is due to the tendency of the center sills to buckle upward under end shock.

An analysis of the results shown under Fig. 8 seems to indicate that the vertical acceleration must be due to the fact that the center of draft is below the center of gravity of the center sill section. This is on the assumption that the test cars are of the A.R.A. underframe construction, in which case there is an eccentricity of 1 in. or more. Under these conditions, if the center sills were free, we should expect the greatest vertical acceleration at the center of the car. The reason this is only 0.28 as against higher readings between the center of the car and the end of the car, seems to be due to the resistance to upward deflection at this point offered by the two cross-bearers located at the door posts.

It would be interesting to make similar experiments with a fish-belly center-sill car, from which we should not expect much upward deflection at the center of the car, but perhaps should expect some at the bolster.

If these conclusions are correct, the solution would require the center of draft to coincide with the center of gravity of the center sill section.

The writer questions the advisability of decreasing the radius of the back of the journal-box wedge from 78 in. to 24 in., unless it has been found that the force is not sufficiently concentrated to crush the material in the roof of the box.

Until tests prove otherwise, it seems that the loaded spring plank will keep the side frame from rocking due to lateral forces applied by the bolster, and in this way prevent concentrated loads at the shoulder or collar of the journal. It must be remembered that to dispense with the spring plank also removes a convenient means of attaching brake-beam supports or guards.

[2] Consulting Engineer, New York, N. Y. Mem. A.S.M.E.
[3] Chesapeake and Ohio Railroad, Richmond, Va.

ALAN N. LUKENS.[4] Years of study on the question of improved springs for freight cars and the examination of many ingenious inventions in this line have shown that some very basic principles have been overlooked or ignored in most of such schemes and designs, including the present well-known A.R.A. standard bolster springs.

The first of these basic principles is that any spring used, regardless of such appliances as may be introduced, should be designed by the best modern methods so that the stresses developed at all critical points may be accurately known and maintained within the limits proved to be the best by life tests and practical experience. Most of the springs in use, including the A.R.A. standards, were designed many years ago before scientific research had shown beyond doubt that the stresses in them were far higher than anticipated. The A.R.A. springs were designed for a stress of 80,000 lb. per sq. in. at the solid height, while modern methods applied to them show they actually develop 93,000 lb. per sq. in. at that point. Furthermore, while the stress developed by their rated loads is not far from reasonable, the modern practice of our railroads of loading cars up to axle capacity regardless of the springs simply subjects the springs to stresses far beyond the reasonable limit.

The second basic principle has been the subject of the author's investigation, namely, the prevention of vertical harmonic vibration. Elliptical springs during movement generate considerable friction between the leaves. This friction if properly utilized prevents the starting of harmonic vibrations, which fact has led to many attempts to add some friction or other elements to helical springs that they too may prevent the vibrations. As early as 1882 United States patents were granted for the so-called "graduated" bolster spring. This consisted of several rather small springs of normal bolster-spring length grouped around a very large, stiff spring of shorter length. It was hoped when compression of the smaller springs encountered this short, stiff spring, vibrations would be broken up or prevented, though the expression harmonic vibrations was not then used—ease of riding being used in their claims. Then followed in 1899 the McCord dampener and in 1901 the Shea controller, both of which added a little friction, and for which many claims were made for great reduction in the number and extent of vibrations. Neither succeeded in accomplishing very much, and excessive wear soon removed them from the market. Then followed a period of inaction in this field until in recent years attempts have been made to secure results by the use of stronger and stiffer springs or simply by using a greater number of the standard springs without any attempt to control the vibrations.

When the author conceived the idea of his snubbed spring he at once stepped so far beyond his predecessors that nothing short of scientific research and the accumulation of sufficient data could render sound judgment of his accomplishment.

Observation of the action of his snubbed springs demonstrated very clearly the vast improvement such springs make over the standard groups. While the charts in the paper speak for themselves, a most dramatic picture of this improvement can be obtained in a very simple way. When the train is running at a speed over 35 miles per hour, stand in the safe passage provided between the cars with one foot resting on the platform of either car. In this position one foot will receive but slight jolts without repetition of sequence while the other foot is doing a regular tattoo jig step so rapid and violent that it will be impossible to keep that foot down on the platform even with the knee loosely flexed.

Without a doubt these snubbed springs effect a remarkable reduction in the rapidity and severity of the vibrations and the author is to be congratulated on his excellent work and on his accomplishments thus far.

The writer believes a still further gain in checking vibration can be secured by the use of springs meeting the terms of the first basic principle outlined above, even to the full extent of eliminating all harmonic vibration throughout the full range of present or future train speeds, and suggest that full trials be made of such springs, particularly in combination with some of the known friction devices not mentioned in the paper. The writer would also suggest that in all new designs of trucks consideration be given to providing increased space for springs. Room should be provided for groups 12 in. wide instead of the present standard of 11 in., together with an inch or more in height. Much good can be accomplished on existing trucks with their restricted space, but the full advantage can only be gained by providing more space in future trucks.

L. K. SILLCOX.[5] The author has pointed out that the minimum proportion of the load on one side of the truck sufficient to keep a wheel from mounting the rail on curves due to flange pressure is 30 per cent if the load on one truck is not more than 16 in. from the center. It is not clear just what is meant by the load on the truck, that is, whether it is the light weight of the car body or the weight of the car body plus the lading. If we take, for example, a 50-ton car as being typical, having a light weight of 45,000 lb. weight of trucks 5000 lb. and maximum lading of 124,000 lb., we find that the light weight on trucks is only 40,000 lb., while the loaded weight on trucks amounts to 164,000 lb. and the weights on one truck (cars with 2 trucks) are 20,000 lb. and 82,000 lb. for light and loaded cars, respectively. With 30 per cent of the load on one side of the truck as the minimum requirement to keep the wheels from mounting the rail on curved track, the loads on one truck of the same car are 6000 lb. and 24,600 lb., respectively, for light and loaded car. Theoretically speaking, the wheel-flange pressure, or rather the reaction of the rail against the wheel to overcome the centrifugal force imparted to the truck in rounding a curve, is in direct proportion to the weight on the truck. However, this is only true when a car is running at a certain speed on a curve having superelevation to suit that speed, so that the car body is normal to the track. Such conditions do not obtain in actual railway practice and a question is raised as to whether or not the derailment tendency of cars on curves is also a function of the weight of the car besides the weight distribution on both sides of trucks as pointed out in the paper.

It is stated that the track warp between truck centers, rather than the warp between wheels on one truck, results in a derailing condition based on the contention that there is enough flexibility in A.R.A. standard trucks to permit one wheel to go down the maximum depth of depressed rail joint without losing its share of the load on this side of the truck. Following the same reasoning, it would appear that a longer truck-centers distance as compared to the wheel-centers distance would also obviate any such unequal distribution as to set up a derailing condition.

Car-body roll or nosing induced by harmonic spring vibrations is a common source of trouble resulting in damage to the lading, particularly of live stock and perishable freight. There is still another serious objection to such harmonic vibration when the periods of spring vibration coincide with the bridge vibration. In this case an unduly high stress is set up in the bridge structure and further experiments on truck springs might well take this feature into consideration.

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[5] Vice-President, New York Air Brake Co., New York, N. Y. Mem. A.S.M.E.

As to the damaging effect resulting from end shocks, it would appear that this is not within the province of proper truck design, and only suitable draft-gear construction may well overcome or minimize this feature.

The truck spring planks as employed on A.R.A. standard trucks are the only rigid cross-tie between the two sides of the truck, and may be relied upon to square the truck on entering tangent-track curves. Some modification in construction rather than its entire elimination would appear to be more desirable.

W. P. BORLAND.[6] Whether or not the author's conclusions as set forth in the paper are fully substantiated, the writer is not in position to say. He is convinced, however, that the author has accumulated a mass of fundamental data concerning the behavior of car trucks under the varied conditions of actual service which should be of far-reaching importance and value in improving the design and construction of equipment of this character to meet the severe requirements of present-day freight-car service.

The accident records of the Interstate Commerce Commission reflect the very great need for measures to correct the causes and reduce the number of derailments. A comparison of these for the first and last 10-year periods for which statistics have been compiled, namely, the period 1902 to 1911, inclusive, and the period 1920 to 1929, inclusive, shows that during the first period there were 61,329 collisions and 56,136 derailments; during the second period there were 57,382 collisions and 136,758 derailments, a decrease of 3947 collisions and an increase of 80,622 derailments. The property damage from collisions for the first period was $48,235,952 and for the second period $57,450,943, an increase of less than $10,000,000; from derailments $48,965,656 for the first period and $159,635,736 for the second period, an increase of more than $110,000,000. It should be borne in mind that these amounts refer only to damage to railway property and do not include amounts paid for lost or damaged lading, personal injuries, or other claims growing out of such accidents.

These figures show the very marked upward trend in the number of derailments, whereas the number of collisions has been kept within less extreme limits. A great deal of thought and effort and large expenditures have been directed toward the prevention of collisions. During the period covered by these accident statistics the commission has prescribed specifications for automatic train-stop and train-control devices and has required their installation on a considerable number of railroads. During this period extensive additions to and improvements in signaling and interlocking have been made. While these improvements in operating conditions and practices were being effected there has also been development of power which has resulted in increase in the length and speed of trains and reduction in the number of trains operated, a condition which tends to reduce the danger of collisions, but which may contribute materially to the causes of derailments.

Examination in detail of the accident record for the year 1929 discloses that of the total of 9871 derailments reported, 4510 were due to defects in or failures of equipment, while only 2080 were due to defects in or improper maintenance of way and structures. There were 6643 train accidents due to defects in or failures of equipment, of which 1342 were attributed to trucks and 1867 to wheels and axles.

In considering all of these statistics the fact should be borne in mind that they include only those accidents which resulted in death, personal injury, or property damage amounting to $150 or more. It is a matter of common knowledge that there are a large number of similar accidents not sufficiently disastrous to be included in these statistics but which are a constant source of delay and expense to the railroads and of trouble and worry on the part of railroad operating officials.

Research work of the character conducted by the author is therefore directed along lines which should be productive of important results. It is of direct interest to the Bureau of Safety of the Interstate Commerce Commission, and should certainly enlist the active support of railroad officials who are responsible for the design, construction and maintenance of cars and for safe, efficient, and economical operation of the railroads.

J. A. PILCHER.[7] Since the paper indicates that, in a measure, the reason for the main car troubles is lack of uniform surface of the track when under load, brought about largely by the influence of the rail joints, it may not be amiss to call attention to the method of track construction as discussed by W. B. Potter, Engineer, Railway Engineering Department, General Electric Company, in the *Railway Age* of February 17, 1923, page 423, in which he discusses a method of track laying which he terms "asymmetrical," and which will give the lateral strength and all of the advantages of the almost universal practice of diagonal track laying, at the same time doing away largely with the tendency for oscillation of the car when the speed is such that this oscillation synchronizes with the low joints. The claim is that the irregularity of the rail joints, one side as compared to the other, would, in a measure, break up the oscillation. The article does not say that this experiment has ever been carried out, but reads as follows:

> The writer suggests that it might be possible to secure the advantage of diagonal joints in respect to track maintenance and the steadier running quality of square joints by laying the track with joints asymmetrically spaced; that is, instead of overlapping a half rail length, to overlap between one-quarter and one-third, preferably a length of lap that would not be an even fraction of the rail length.

With the longer rails that are now being used, viz., 39-ft., there would seem to be no particular disadvantage in this suggested arrangement.

The question really to be determined is whether the advantages to be gained, either with the change in the track or change in the springs, are sufficient to warrant the possible expense.

G. M. EATON.[8] Hope has been held out that alloy steel might solve the epidemic breakage of freight-car springs. In an intermittently prosecuted development program extending over a good many years a persistent effort was made to develop a high-grade alloy-steel spring for heavy fatigue service which would give a life better than the standard carbon-steel spring.

About twenty different high-grade alloy steels were tried. On fatigue test the best individual spring of alloy steel failed at about half the average number of cycles achieved by carbon steel.

It was found comparatively recently that the reason for the early failure of the alloy steels lay in the condition of the surface. The mill-finished surface of most high-grade alloy-steel bars, of a type and size apparently adaptable for freight-car springs, is less well adapted to coiling and quenching operations than the corresponding surface of carbon-steel spring stock. The two major types of surface inferiority are decarbonization and seaminess. Often this surface inferiority of the alloy steel cannot be recognized by the naked eye, but a deep etch is most revealing for seams.

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[7] M. E., Norfolk & Western Railway Co., Roanoke, Va. Mem. A.S.M.E.

[8] Spang, Chalfant & Co., Inc., Ambridge, Pa. Mem. A.S.M.E.

The only commercial way known to date of capitalizing on the merits resident in high-grade alloy steel for heavy helical springs in fatigue service, is to remove the inferior mill-finished surface. This may be done commercially by centerless grinding or turning. When this is done we are justified in looking for longer spring life in existing freight cars. But it is most doubtful whether we can expect permanent springs in this service due to the excessive stress to which attention has been called.

In connection with this comparatively recent discovery that the stress on the heavy standard freight-car spring is 60 per cent higher than intended when the spring was designed, we can have a little comfort from the fact that the nominal working stress is not $80{,}000 \times 1.60 = 128{,}000$ lb. per sq. in.

This equation overlooks the fact that when the as-rolled free height of the spring is reduced by the setting operation, the material of the spring on the inside of the coils is stressed far beyond the elastic limit and flows plastically. When the setting load is removed and the spring assumes its final free height, this material at the inside of the coils is in a state of negative stress of fairly high degree. As working load is increased this stress passes through zero and then builds up as a positive stress that is too high for permanent endurance.

The comfort we can gather is only to the effect that the working stress is less than 128,000 lb. per sq. in. The springs still break from overstress.

There is a further improvement of springs that is theoretically possible, and in the writer's judgment entirely practical.

Many of the commercial coil-spring quenching rigs cool the inside of the coil material more slowly than the material at the outside of the coils. This results in the anomaly of a spring which is weak in the regions of maximum stress and strong in the regions of minimum stress. It is entirely possible and practical to arrange a quenching rig which reverses this condition and results in a spring whose strength is distributed in the same general manner as its working stress. This is not being done today in any commercial quench with which the writer is acquainted. In any research looking toward the development of low-maintenance freight-car trucks, this method of quenching is well worth developing to a practical production stage.

W. E. Symons.[9] The paper is of especial interest to the writer since the author's conclusions fully confirm some similar findings reached several years ago following quite extensive service tests, although the writer's methods of procedure were different in many respects.

Several years ago two Western trunk lines built some 6000 modern refrigerator cars for the California fruit traffic, but when placed in service derailments were so frequent as to interfere with all traffic.

After much correspondence and considerable controversy, the writer as a neutral expert was employed to ascertain the cause and apply proper remedies.

After a careful study, one car was fitted with an adjustable center plate so that the writer could not only observe, but actually measure the force of lateral energy of car body delivered to the wheel flanges at the rail. To facilitate this work a platform box was built extending from end of car under the truck axles, and when riding in this box in a semi-recumbent position, one could not only clearly observe the behavior of car body and trucks, but take readings, make notes, etc. of all important factors.

In this observation box only a few inches from the rear wheel, the writer often noted the car body rolling to such an extent as to lift the wheels up from the rail far in excess of the flange depth, while on entering or leaving double-S curves, due to rigidity of the car-body superstructure and defective track, the car body would rest on the forward and rear diagonally opposite side bearings, not infrequently being clear of one or both center bearings.

It was also found that cars which rolled violently at a certain speed, would cease rolling at a higher or lower rate of speed, wheelbase, rate of speed, and track conditions being the governing factors, while side-bearing location and clearance were considered.

After very extensive road tests on heavy gradients with sharp curves in a mountainous country it was decided to replace the M.C.B. center plates with the concave and convex type, sometimes called the ball-and-socket type, and provide lateral play to truck bolster by using the Barber rollers.

With the two above changes in car design and proper repairs to the track as to surface and alignment, the derailments and wrecks ceased, as this equipment was then safe for movement at all permissible speeds.

The author's findings not only coincide with those of the writer, but his views on the problem in general gives the latter courage to speak in detail on a subject that for years has been sadly neglected.

We now come to the financial feature of the problem. As there are about 2,300,000 freight-train cars, there would be about 4,600,000 trucks to replace or exchange. The items of maintenance expense involved by this exchange would be as follows:

Freight-train car repairs	$335,000,000
Proportions of track and bridge repairs	415,000,000
Total	$750,000,000

It would be interesting, if in connection with this splendid analysis, the author could give some estimate of the costs involved and economies that might be expected to result therefrom.

George G. Floyd.[10] The work done by the author with his research cars has developed the fact that springs are a very important item in the make-up of the average freight-car truck.

One of the distressing characteristics of a coil spring is that certain speeds even on reasonably good track may cause the car to vibrate violently vertically with disastrous results to the car loading. With equipment of the average capacity and weight of today, this critical speed for vertical oscillations of the springs of the car body is around thirty-five to forty-five miles per hour, depending upon the weight of the car body and its load. Therefore, until just recently, with the slower freight-train speeds of years ago, this question of vertical oscillations of the car and its load did not enter into the problem because the speeds at which this occurred were not reached.

From a reading of the paper it would seem that the ordinary four-wheel truck of today is a reprehensible device. The four-wheel truck, of course, like all other mechanical devices has certain inherent bad qualities; but, considering the service that it has given for the last fifty years, it is probably not entirely to blame for all the ills and ails and difficulties in the operation of freight cars. A six-wheel truck is probably better, but it is too expensive for the average freight car. Two wheels would be cheaper than four, but while our friends abroad have been more or less successful with a two-wheel truck, it has never been popular in this country.

I object somewhat to condemning the four-wheel truck and putting on it the entire burden as there are other parts of the entire railroad system that are not entirely without blame. The track has something to do with the question, the air brakes are not entirely blameless, and the locomotive engineers are not entirely without fault. I protest against the apparent disposition today to make the four-wheel truck carry the entire burden. Some years ago the writer participated in an investigation of

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[10] Mechanical Assistant to President, American Steel Foundries, Chicago, Ill.

a series of approximately two hundred derailments. These derailments were on a single division of the road and there were twelve engineers involved in handling all the trains on this division. As he remembers it, fifty per cent of the derailments were chargeable to two engineers. There were four engineers who had no derailments and the balance of fifty per cent of derailments were charged against another four engineers.

One of the difficulties was the particular manner in which brake applications were made; while the track and the equipment, of course, had a contributory value, the fact remained that improper handling of brakes produced derailments and proper handling of brakes avoided derailments.

In another investigation of something like fifty derailments of long trains, the car that went off the track was invariably within five cars of being in the middle of the train. The cause of these derailments was a combination of air brakes, speed, and track conditions, each probably equally important. It would therefore seem the proper manipulation of the air brake system in stopping the train plays quite an important part in the matter of derailments.

An arrangement has been made whereby the author has turned over his research cars and equipment to a committee of manufacturers who in connection with his own research engineers will conduct a more or less elaborate series of experiments along the line already indicated in the paper. This committee hopes eventually to secure the cooperation of representatives of the railroads in the use of this research equipment to carry on an investigation that will be of great benefit to all concerned, and the author is to be congratulated upon the spirit with which he has entered into this arrangement.

Author's Closure

Mr. Clark calls attention to the fact that the details of the author's improved truck designs are not discussed. The reply to this is that the paper has to do with general research on the subject, applicable to all trucks and to no one truck in particular.

Regarding his statement that "the spring plank may put the truck permanently out of square instead of squaring it as intended"—the writer assumes that, in this connection, Mr. Clark refers to the possibility of the spring plank holding the bottoms of the side frames apart a different amount than they are held apart at the top by the bolster. We are all familiar with the fact that many cast-steel side frames and bolsters have been in operation for over twenty years without any appreciable wear between the side frames and the bolster, and we also know that, on some similar trucks, this wear is very excessive after one or two years' service. It seems to the author that there is no explanation for the latter case except the fact that these rapid-wearing trucks are held permanently out of square across the rails by the spring plank.

On one lot of 2500 cars built in the last few years, inspection showed that a large number of trucks were as much as 1 in. farther apart at the top of the side frames than at the bottom of the side frames. This came about from the following causes:

1 Allowance for shrinkage in cooling was not made in the dies for punching the spring planks hot, and therefore the spring planks were all short between the pressed holes for side-frame bosses.

2 The bolsters ran to maximum length.

3 The distance from the center of the spring-plank bosses on the side frame to the inside of the columns of the side frame was entirely too great due to error in the side-frame pattern and to a lifting of the spring-seat core of the side frame in the mold.

So far as the author knows, no railroad or steel company gages the distance between the center of the bosses on the spring seat of the side frame to the inside of the columns on the side frame. Certainly we shall have less wear if the side frames can adjust themselves to give uniform spring load over the entire spring seat, and, in the author's opinion, the elimination of the spring plank will help this condition.

This particular wear, resulting from the two side frames not being parallel, comes on the inside or outside faces of the frame columns and on the column guides on the bolster.

If the center plate bearing on the bolster, the spring seats on the bolster, and the spring seats on the side frame are not in parallel planes, there is a resulting rapid wear between the bolster and the frame columns. If the truck gets out of square by having one frame go ahead of the other, there is also a resulting rapid wear between the bolster and the frame columns.

It is readily seen that the breakage of any coil in a spring group may result in a lack of normal adjustment between the bolster and the side frames, which is another reason for the desired elimination of spring breakages. Under all of the non-adjusted conditions mentioned, harmonic spring oscillation results in rapid wear.

Where lateral motion is obtained by the continuous relative material motion between the bolster and the side frame, rapid wear can result, even without harmonic truck-spring oscillation.

Mr. Herter apparently overlooks the fact that, with standard trucks supported on the center plate, it is not practical to bring the side bearings close together in order to prevent the car body from overturning under severe conditions, because the outside supports would have to be so far separated on the body and truck bolsters that they would not be effective. For complete safety, the tilting action between the body and truck bolsters must be sufficient to permit the body bolster to come down on top of the side frame in an emergency, and the fulcrum for this tilting action must be much closer than 25 in. from the center of the rails. The outside bolster support on the author's truck does not function at all unless and until lateral motion materially moves the body bolster in relation to the truck bolster.

Regarding the possibility of something lodging on the rocker seat on the truck, we have done our utmost to find some way in which this could be accomplished with the trucks under the cars, but have been unable to find any way in which the truck could be disabled.

These research cars have U.S.R.A. center-plate height and the center line of draft is on the center line of the sills so that there is no eccentricity of sill loading from end shock. The load in these cars under these end-shock tests consisted simply of twelve water tanks weighing about 18 tons per car. It will be noted from Fig. 8 how this load is distributed in the cars. It has seemed to the author that end shock would tend to rotate the load mass in each end of the car around its own center of gravity, which would seem to account for the upward buckling of the car frame under end shock.

Regarding reducing the radius on the back of the wedge from 78 in. to 24 in., the author would call Mr. Herter's attention to the fact that five hundred 100-ton coal cars have been operating on the Norfolk & Western Railroad for over ten years, with the entire body load supported on four rockers. The product of the length by the mean diameter of each of these rockers gives a wear factor of 156, and there has been no evidence of crushing of the material in the rockers or in the rocker bearings. With a 24-in. radius on top of the wedge, there is a similar wear factor of 336, and as there are eight wedges per truck, as against two rockers per truck, it is evident that there is more than four times the wear factor on a 70-ton car than has been found entirely efficient and satisfactory on a 100-ton car.

The author is unable to see Mr. Herter's point in reference to the spring plank keeping the side frame from rocking due to

lateral forces applied by the bolster. These lateral forces must be resisted by the two journal collars or shoulders, and the nearer these reaction points can be held in line with the point of application of the load, which is the bolster, the better it will be.

Regarding the attachment of the brake-beam safety supports to the spring plank, the author would call Mr. Herter's attention to the fact that a large number of Verona cast-steel trucks have been in service for a great many years. These trucks have no spring planks and the brake-beam safety supports are fastened to the bolster. A careful investigation has indicated that there has never been a failure of this type of safety support.

Referring to Mr. Lukens' theoretical discussion on truck springs, the author thinks he is right, in that truck springs develop a higher fiber stress at closure than the old formulas indicated. However, the author is strongly of the opinion that these slightly higher stresses at closure can be entirely overlooked if we eliminate harmonic spring vibration and car roll so that the springs will never close.

Regarding Mr. Lukens' statement that the friction generated by elliptic springs, if properly utilized, "prevents the starting of harmonic vibration," the author is inclined to the opinion that the absence of harmonic vibration on passenger-car springs is due more to the very flat load curve of these springs than to friction. The flatter the load curve, the slower is the critical speed for harmonic vibration. This critical speed for passenger cars, to produce harmonic vibration, is so slow that this velocity factor in harmonics is negligible and somewhat similar to the harmonics in a well-designed automobile spring with long travel, which is not objectionable.

The snubbed springs that Mr. Lukens refers to do actually break up excessive harmonics, and the springs will never go solid under any conditions. There is, however, one objection to the snubbed spring, and that is, under harmonic vibration, when the bolster hits the snub, it can be definitely felt in the car and it is objectionable. Experiments are now under way to definitely break up this harmonic vibration with what might be termed yielding snubs to obviate this objection.

The author is sure that, if Mr. Sillcox will read the paper over again, he will see that, in all discussions of cross-equalization of the load, the author refers entirely to the load above the truck bolster and it is immaterial whether the car is light or loaded. In the analysis of what proportion of the load of one end of the car body is on one rail and what proportion is on the other rail, this is a simple matter of leverages. If this load is concentrated at 25 in. from the center of the rails, the body load on one rail is 15 per cent and on the other rail it is 85 per cent. If the body load is concentrated at $15^1/_2$ in. from the center, the percentage of this body load on one rail is 30 and on the other rail, 70.

The author cannot agree with Mr. Sillcox in his analysis of the effect of centrifugal force in connection with derailments. As a rule, the superelevation on a railroad curve is higher than is needed for freight service and lower than is theoretically correct for high-speed passenger service. For this reason, the author does not believe that we ever have a high flange pressure against the outside rail due to centrifugal force from the truck mass. The centrifugal force on the car body tends to throw this mass toward the outside rail and the principal reaction is downward on the outside rail, although there is a lateral component of this action toward the outside rail. It seems to the author impossible for this action to ever cause a derailment because, with standard trucks, under this condition, 85 per cent of the body load is then on the outside rail. Centrifugal force is, the author thinks, contributory to derailments only because it results in an initial roll of the car body toward the outside rail, with a quick return of the car-body roll to the inside rail, and it is under this condition that the car will sometimes derail, because then only 15 per cent of the load is on the outside rail. This is true whether the car is loaded or whether it is light.

Regarding the derailing condition from track warp, this is, in the author's opinion, a function of the resulting warp between the four side bearings, and if the car body is sufficiently flexible, no derailment will result from track warp. Increasing the distance between truck centers, it seems to him, would only help to the extent that a longer car would have greater flexibility than a shorter car of the same construction. It must not be overlooked, however, that if the warp in the track results from superelevation to level, the warp between truck centers will increase in exactly the same proportion as the cars lengthen. Mr. Sillcox is right that truck design has nothing to do with damage from end shocks, but with these research cars this very important subject can be scientifically studied in connection with both longitudinal and vertical shocks to perishable ladings.

The author cannot agree with Mr. Sillcox that "the spring plank provides a rigid cross-tie between the two side frames of the truck and may be relied upon to square the truck on entering tangent track curves." If the spring plank was riveted to each side frame, this effect would be obtained, but riveted spring planks are no longer used.

Mr. Borland's discussion, giving statistics of railroad operation in this country is, of course, very interesting and particularly so in connection with modern operation. It is very clear that, in spite of all the railroad safety campaigns in this country, freight-car derailments, with loss of life and damage to property, are not decreasing, and the author stands on the flat statement that, in his opinion, any railroad track that is safe for a locomotive should be more than safe for any freight car.

Mr. Pilcher, who is keenly alive to the desirability for eliminating derailments and harmonic spring vibration, suggests a change in the laying of the rails to break up the present synchronization of the rail joints in connection with harmonic spring vibration and car roll. It is possible that, by relaying our track in this manner, something might be accomplished, but it seems to the author that Mr. Pilcher is carrying on the very old practice of mechanical men of "passing the buck" to the maintenance-of-way engineers. In the author's opinion, the mechanical men should exhaust every possible means for making freight cars safe on track as it is. It is perfectly obvious that no cure obtained either by changing the trucks or changing the track will be adopted if the advantages to be gained are not out of all proportion to the expense involved.

Mr. Eaton discusses the freight-car spring from a theoretical angle, not only in connection with the use of alloy steels, but also in connection with the method of manufacture. Railroad men naturally lean toward the cheapest material they can buy, and to a method of manufacture that is not a laboratory proposition, but that will apply to quantity production.

Very recently the truck-spring manufacturers of this country have greatly improved their methods of manufacture and the resulting specifications, and the author is sure they would welcome any offered possibility for increasing the quality of their truck springs, provided the cost of manufacture is not increased beyond the willingness of the purchaser to pay for the added value.

Mr. Symons' personal study of the behavior of freight-car trucks is very interesting. He states that some 6000 modern refrigerator cars could not be kept on the rails, but that the derailments ceased when the cars were equipped with ball-and-socket center plates and with the Barber lateral motion. He also states that, at the same time, proper repairs were made to the track in connection with both surface and alignment. The author does not see how we can draw a definite conclusion, covering this lot of cars, as to whether the derailing conditions were

improved by the changes in the trucks or the improvement in the track. From his own experience the author is unable to see how these particular changes in the trucks could help the derailing condition, and he would conclude that the improvement in the track was responsible.

In regard to Mr. Symons' observation of the lift of the wheels from the rails under the influence of car roll, the author would state that with every truck tested under his research cars, where the side bearings were spaced 50 in. apart, he has seen the wheels lift off the rails from car roll. These research cars are now being equipped with accurate means for measuring the maximum amount of wheel lift from the rail on any run, and to give a continuous record on a chart of all wheel lifts of $^1/_4$ in. or more. With this superimposed record, it will be possible to determine exactly how much roll is necessary to lift the wheels off the rail on any car.

Regarding Mr. Symons' statistics in connection with the financial aspect of this matter, it is impossible in a short time to go into the question of the economies that might be expected to result from perfected trucks. The author's general feeling in this connection is that any railroad is willing, at any time, to make a 50 per cent investment, but they would have to be very sure that the investment of $1.00 would certainly produce a return of 50 cents each and every year.

The author hopes that Mr. Floyd does not feel that he is condemning the 4-wheel truck for freight cars. He thinks it is the only possible truck for freight cars up to 70 tons capacity, but is sure that Mr. Floyd is in entire agreement with him that it is our duty to perfect this 4-wheel truck as far as it is possible, provided, of course, that this can be done economically.

Mr. Floyd refers to an investigation where it was found that out of two hundred derailments on one division of a railroad, two locomotive engineers out of twelve were hauling 50 per cent of the derailed trains. He does not state whether these two locomotive engineers were discharged or disciplined. The author is fully conscious of the human factor in railroading, and it is impossible to have all locomotive engineers 100 per cent efficient. If the delinquencies of these two locomotive engineers only showed in these derailments, it appears to the author that we can do a great service if we make our freight-car trucks so foolproof that we can operate safely with engineers who are not 100 per cent efficient.

This research work is still in progress at Baltimore and will continue until bad weather. It is hoped and believed by our joint committee of truck and spring manufacturers that, by the early summer, we shall have formed very definite conclusions as to what we believe to be the best possible truck construction from every angle, and we shall then be very glad to make a complete demonstration of our findings to any railroad man who is interested.

Progress in Textile Manufacturing

Contributed by the Textile Division

Executive Committee: Edwin H. Marble, *Chairman*, McRea Parker, *Vice-Chairman*, Wm. L. Conrad, *Secretary*, Earle R. Stall, Henry M. Burke, and Paul A. Merriam

THE year 1929 has shown a marked improvement in the attitude of textile-mill owners toward the adoption of better machinery and methods. Consequently, the more progressive manufacturers have been able to improve their product and at the same time reduce their costs, with the result that many are showing profits while the industry in general is considered to be still in a state of depression. At the same time, many mills of proved inefficiency, for want of progressive leadership or capital, have been forced to close. Continuation of this trend will inevitably bring to the front a group which will continue in business and make money, while others will have to go out of business, and the result will be to put the industry in a healthy situation again.

The machinery manufacturers, appreciative of this situation, are bending their efforts to improve their equipment, and those that are successful are taking orders. This improvement is generally shown in the adoption or more general use of anti-friction bearings, cut gears, etc., in an effort to reduce vibration to a minimum.

Demand for Engineers

As a result of this tendency toward improvement in methods within the factory and the machinery developed for the industry, there is an increased demand for trained men from textile and engineering schools. The plant engineer has definitely taken his place in industry, and the more progressive textile concerns are availing themselves of his services. This is resulting in a breakdown of many of the rule-of-thumb methods, and the substitution in their place of machinery and control based on scientific principles.

This interest in scientific methods has created a demand for more and better equipment for the testing of materials at various stages of manufacture. As an example of this, an improved machine has been placed on the market during the year for bursting tests on knitted fabrics which gives more uniform results than previously were obtainable.

Humidity Control

There is a growing appreciation of proper humidity and its accurate control, and this is being applied not only in more mills than formerly, but over a wider range in the individual mill. Numerous installations have been made during the year. Developments in this line will undoubtedly lead to more knowledge of the subject and to improved control.

New Materials for Machinery and Equipment

In the effort to obtain improved operation of machinery, there has been a search for improved materials of construction, and some of the newer materials, such as those embodying artificial resins of the nature of bakelite, have been introduced. These have found their place in bobbins, spools, pickers, etc. In rayon manufacture, alloy metals have to a considerable extent replaced glass where acid-resisting qualities were required.

Rayon

The processes and machinery employed in the manufacture of textiles are fundamentally similar though used on various raw materials. These latter include the so-called "synthetic fibers," generally referred to as rayon, but because this material is a chemical product and relatively new, whereas other textile materials are natural and have long been in use, it appears well to give it separate consideration.

The marked increase in the output of rayon is in itself worthy of note. Factories have continued to spring up in almost mushroom fashion, both in this country and in Europe. Many European concerns are establishing factories in the United States an Canada. As result of this growth, and the concurrent demand for the product, the output of rayon for the calendar year 1929 can be safely estimated at close to 400,000,000 lb. This phenomenal growth is significant, for it brings out the fact that rayon is replacing other materials as well as finding novel uses of its own. Much machinery previously used on other fibers is being converted to the use of rayon, while at the same time new machinery is being designed for its special use. Considerable progress has been made in this direction during 1929.

While rayon is still manufactured under four basic processes, namely, the viscose, acetate, cuprammonium, and nitrocellulose, many modifications have been made in these with the result that a near approach has been made to real silk, both in fineness and appearance. At the same time its other properties have been improved, resulting in greater resistance to heat and better affinity for dyes. Hosiery made entirely of rayon is now a fact, and a rayon sewing thread has been placed on the market during the year.

Preparation of Fibers

In the matter of preparation, which applies in general to all forms of raw textile material, greater attention is being paid to grading and cleaning of the material used. This has been especially true in cotton, because of attempts to use lower grades which are mechanicaly picked and less carefully ginned. This has resulted in radical improvements in machines for opening, blending, cleaning, and picking. Machinery which has been developed for cotton has found application, with some minor alterations, to wool, with substantial results. This dual application has permitted some degree of standardization, with resulting economy in manufacture and sale of this equipment.

Carding

In carding, greater attention is being paid to more uniform webs, with corresponding reduction of variation in counts. To this end, a more accurate weigh box has been introduced during the year and an improvement made on the Scotch feed. This improved feed lays a wider and thinner sliver than previous feeds, permitting a greater degree of overlapping of the sliver, with correspondingly greater smoothness and uniformity in the rovings taken from the card.

Cut rayon stock, too, is being carded with a greater degree of success through the better working knowledge of materials and special arrangements for their proper handling. Proper control of humidity and temperature has played an important part in this improvement.

Advances have been made in the kind and quality of oil supplied the textile trade for the lubrication of the stock. Research has produced oils of mineral bases which are successfully replacing the more expensive vegetable oils. Greater attention is being paid in the mills to the kind and quality of oil used and its method of application, resulting in better working of the stock.

Spinning

Perhaps the outstanding development in spinning is the application of variable speed to the spindles. This permits giving more equal tension to the yarn throughout the spinning cycle. Unequal tension was the result with constant-speed spindles because of the tendency of yarn to become tight where the effective diameter of the bobbins was small, and loose where this diameter was large. Variable speed permits greater production per spindle, as the maximum speed of the spindle is no longer determined by a condition which exists but a fractional part of the working cycle.

Variable speed has been accomplished generally by the use of variable-speed motors directly connected to the individual frames without clutches. In Germany successful experiments are reported in the use of individual motors on fliers.

Another development which is not new but which has received a great deal of attention during the past year is the so-called "mule spinning frame" for spinning woolen yarns from roping taken off a woolen card. This type of machinery has been on the market for several years, but recent improvements have materially altered it so that frames are now available over quite a range of counts. Outstanding among these improvements is the divorcing of the draft rolls from the spindles and driving them independently of each other so that the most productive speed can be assigned to each.

Weaving

Power looms are now designed especially for rayon. These looms are fundamentally the same as the ordinary loom, but have refinements and features which adapt them better to rayon.

The automatic loom has been improved by constructing it heavier and by using anti-friction bearings for the main journals. In addition, more attention has been paid to the kinematics of design, resulting in harness motions of smoother acceleration and head motions freer of variation caused by the picker action. The result is a loom which runs with less vibration and consequently at a higher speed than heretofore has been considered practical.

There is a tendency toward a greater use of the electric types of stop motion since these have been improved over the older electric devices. One of the larger loom manufacturers has conducted successful experiments along this line, and will no doubt offer its improved device to the trade in the near future.

Out of the electric stop motion has grown the idea of complete electric control of the loom. This is accomplished by equipping the loom with an individual motor of the double squirrel-cage type, which is capable of giving a high starting torque when thrown directly across the line. This permits a push-button control of the motor, with resulting facility of starting and stopping the loom from any working position taken by the weaver, which is an obvious advantage.

In the manufacture of rugs there has been a general movement toward looms of greater width in order to meet the demands of the trade. Looms capable of weaving fabrics 15 ft. wide are not uncommon, and equipment for widths up to 20 ft. has been installed. This has involved some very serious problems in design on the part of the machinery builder.

Of passing interest in this connection is a machine capable of making rag rugs by a braiding process. Rag carpeting is now available for the householder of modest means.

Dyeing and Bleaching

With the growing demand for color, new dyes have been introduced which give brighter colors, dye more successfully in neutral baths, and are better able to withstand hard wear. The insistence on fast colors is more general. The use of vat colors has increased on rayon, cotton, and mixed fabrics, also on woolen and worsted fabrics, and to some extent on felts. Dyes have been developed for especial use on rayon with more uniform results. Peroxide bleaching is finding greater use in the bleaching of cotton yarn and piece goods. It is also being used to a greater extent on woolen piece goods to meet the present demand for bleached fabrics in women's wear.

The changing attitude toward technical and automatic control is exemplified in dyeing and bleaching.

Finishing

Marked progress is developing in the direction of grouping finishing-plant machinery in series or ranges. This, among other important advantages, secures elimination of the intermediate handling. Three methods are employed which use, respectively, variable-speed motors, by which variable speed and synchronism are obtained electrically; constant-speed motors or mechanically driven shafts, speed variation being obtained through a mechanical speed changer; and variable-speed steam engines, where control is obtained through the governing mechanism. It is anticipated that this form of operation will eventually be extended to other departments of the industry.

The gradual but certain influence of the cutting-up trade has never been more in evidence than in the past year. Today a wool fabric must be finished, ready for the needle; there must be practically a permanent set not affected by the steam pressing now almost universally used by clothiers, this steam pressing taking the place of the former hand pressing or ironing which the earlier tailors thought necessary. The fabric is subjected to a processing that gives it a clean, even luster, a feel pleasing to the touch, and a set or permanent conditioning that can be depended upon. Several types of machines have been introduced, all embodying the same general principles of steaming the fabric when rolled upon a cylinder, while enclosed in a mantle or wrapper, and exhausting the steam from the body before removing it. This is the system of open steaming, as contrasted to the older closed steaming formerly much in use.

In the cotton trade the changes have been less radical. The use of rayon has brought about a demand for lighter machinery, but of higher speed capacity and capable of closer adjustment. In some types of magazine looms the filling yarns project beyond the selvage and have to be cut off. This has brought into the field shearing machines with nicely adjusted cutting parts and suction devices adapted to bring the projecting ends into the cutting parts, which remove the imperfections without damage to the fabric.

In general, practically all machinery in the finishing departments for all fabrics has had to be redesigned to meet the call for increased speed in the various processes.

Knitting

The production of heavy knitted fabrics closely resembling the woven product has caused no little interest and speculation in the textile field. These fabrics are closely bodied and are finding a ready acceptance for top coatings and heavy overcoating. The fact that a knitting machine produces this fabric many times as fast as a loom could produce its equivalent, has given the weaving trade some food for thought.

Conclusion

This report outlines some of the developments in the textile field during the year. The Committee feels that it is indicative of the greater place which the engineer and engineering methods are taking in the industry. There is need for a freer exchange of ideas among the engineers if the benefits of their practice are to become more general and more pronounced. The textile publications are helping to this end, and it is notable that the leading textile journal of Europe is now publishing an American edition. The Textile Division affords a forum for engineers engaged in the industry. To such extent as textile engineers avail themselves of this opportunity, will they promote the industry to the same healthy basis enjoyed by other industries in this country.

McRea Parker, *Vice-Chairman.*

TEX-52-2

Design and Operation of Range or In-Train Drives for Finishing Plants

By WENDELL S. BROWN,[1] PROVIDENCE, R. I.

Marked progress is being made toward grouping finishing-plant machinery in series or in ranges. This, among other important advantages, eliminates intermediate handling. Range drives may be divided into three classes:

1 Adjustable-speed motors, which include direct-current constant-voltage equipment, direct-current multivoltage equipment, and alternating-current equipment.

2 Constant-speed motors or mechanically driven shafts, speed adjustment being obtained through such a device as the mechanical variator.

3 Adjustable-speed steam-engine drives.

Range drives prove advantageous in many combinations, from cloth in the rope form to cloth in the open form. Examples are given.

The successful operation of finishing machinery in ranges is dependent upon the attainment of certain advantages, such as elimination of in-between losses, improved uniformity and quality of product, saving in power and maintenance expense, and saving in executive work.

There are also certain possible disadvantages, such as the present market tendency toward a multiplicity of small lots and varied styles, and the demand for samples. Range speeds are limited to that of the slowest member, breakdowns tie up production, additional building construction is necessary to accommodate extra length, operating losses due to cloth damage in earlier processes continue unnecessarily through subsequent processes, and there is somewhat greater initial expense.

THE textile industry no longer finds itself exempt from the world-wide demand for more efficient handling of men, machines, and materials. The awakening call here and abroad for organization surveys in all kinds of industries, including the manufacture and the finishing of textiles, is quite apparent, and the necessity for improvement needs no elaboration.

This paper concerns advances in the more efficient handling of machines employed in that particular branch of the textile industry engaged in the art of finishing, which includes bleaching, dyeing, and printing.

Marked progress is being made through grouping certain machines or processes in series or ranges. Range drives may be defined as the successive processing of goods without intermediate handling through separate machines arranged in series, or "in-train," as against the older method of operating individual processes singly. The older methods involve intermediate handling, consisting of packaging, transportation, and storage between machines.

Some of the forms of mechanical range drives are not new, for instance the old rope soaper ranges. Undoubtedly, new combinations, more frequent combinations, and larger groups of machines are now being put into ranges than formerly, and the practice is generally recognized as good. In part, this is due to, and has been the cause of refinements in the development of automatic speed-control equipment. The question now is how much equipment to place in range, the number of machines being limited by economics rather than by mechanics.

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Contributed by the Textile Division and presented at the Annual Meeting, New York, N. Y., December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Types of Range or In-Train Drives

A range drive includes two or more separately driven units or machines. These separate drives are arranged with intercontrol so designed as to insure the proper degree of synchronism under changing over-all speeds and other varying conditions.

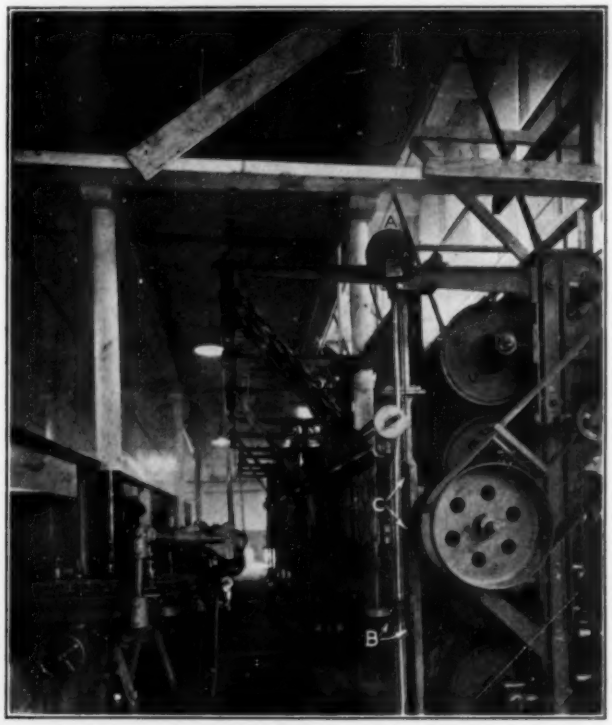


Fig. 1 Installation of Dancer-Roll Control on a Finishing Range Consisting of Mangle, Dry Cans, and Ninety-Foot Tenter

(This automatically maintains proper relations in cloth travel between two different process units operating in tandem, each unit being driven by independent motors operated from a common control. The motors are over 100 ft. apart with no mechanical interconnection. A is the dancer rheostat, B the dancer roll, and C the slot in which the dancer roll travels.)

Range drives may be divided into three classes according to the method adopted for driving the individual units or groups.

Class 1 Adjustable Speed Motors

These are synchronized by rheostatic control for direct-current motors, and usually by brush-shifting elements for alternating-current motors. Synchronizing in some instances is accomplished manually, but is usually most satisfactorily performed by automatic actuation through a "dancer roll" or other mechanism.

A dancer roll (see Fig. 1), also sometimes known as a compensating gate, consists of an idler roll floating upon a fold of cloth

as the latter passes from one machine to another. The vertical movement of this roll is dependent upon the variation in accumulated slackness of the cloth, and is communicated to and operates on the motor-control device. This type of control can be made sufficiently sensitive to act over short distances of roll travel, especially if the control device is of the vernier type, superimposed upon a main regulating device which controls the range as a whole.

Direct-current adjustable-speed ranges are of two types: (A) Constant voltage, using specially designed but now standard motors, with field and armature control, and (B) multivoltage, including the Ward Leonard with standard motors. The former or direct-current variable-speed equipment of the constant-voltage type is very highly developed, and is thoroughly reliable. A typical example of this system of range-control equipment follows:

1 Control from one central push-button station providing the functions of "Inching," "Run" (fast or slow), and "Stop."

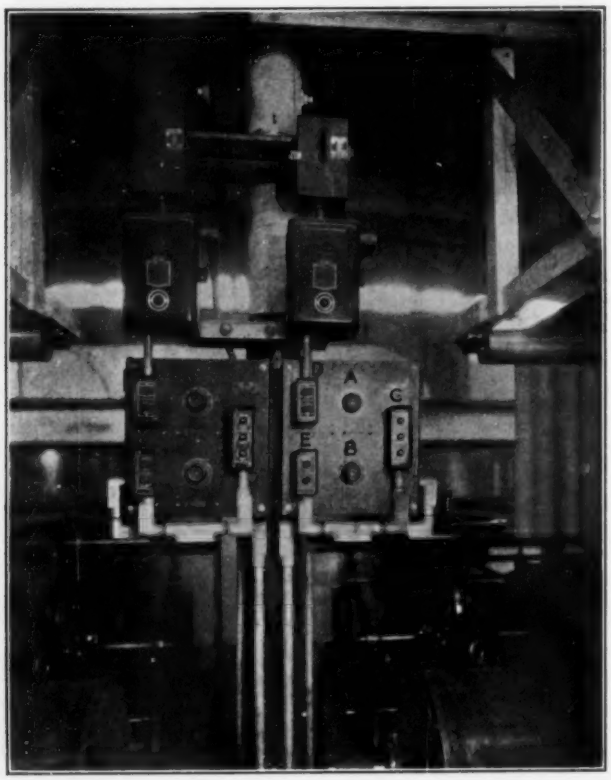


FIG. 2 CONTROL EQUIPMENTS FOR TWIN DRY CANTENTERING RANGES

2 Predetermined speed setting, without necessity of adjusting main rheostat each time, when starting.

3 Automatic time or current-limit acceleration.

4 Dynamic breaking for quick stopping electrically.

5 Interlocked field rheostats for full-field starting.

6 Emergency "Stop" and "Lock-safe" push buttons located where required.

Control is usually accomplished through one main rheostat or a single multiple rheostat, operating in the fields of all motors alike, with fine or vernier individual rheostats for each motor actuated by dancer-roll equipment. There is also the alternative possibility of locating a single main rheostat in each motor field, actuated by the dancer roll, but in this case the follower motor obviously operates in sequence rather than simultaneously with the master equipment.

Typical control equipments for twin dry cantentering ranges are shown in Fig. 2. Each panel makes possible the following centralized control:

Manipulation of rheostat-handle "A" controls the main speed setting of the range drive as a whole. Manipulation of rheostat-handle "B" controls the speed setting of the swing-motion motor from 17 to 51 breaks per minute. Manipulation of push-button station "C" controls all stop, starting, and inching functions of the drive. Manipulation of push-button station "D" starts and stops the swing-motion motor. Manipulation of push-button station "E" controls the operation of the chain-expander motor. With the control equipment are furnished limit switches for preventing over-expansion, or over-contraction beyond permissible limits in the width between chains. There is also furnished a limit switch for automatically centering the swing-motion element of the frames each time at stopping. The motor to drive the tenter frame is 15 hp. with 4:1 ratio. The motor to drive the cans and mangle is $7^1/_2$ hp. with 4:1 ratio operating in tandem with the preceding. A separate 5-hp. motor for independent drive of swing motion is furnished, and also a separate $1^1/_2$-hp. reversing motor for width control between chains.

In some cases the dancer-roll control is omitted altogether in range drives. For instance, in a mercerizing range, when from power or stretch considerations it becomes desirable to get the cloth out of the caustic to the frame in the least possible time, the slack or extra travel required through a dancer roll is considered detrimental to the most efficient processing of the fabric. In such instances where the direct-current constant-voltage system is used, it is not unusual to take the cloth in open form direct from the padder to the frame without going through the dancer roll. In this case, one setting of the vernier rheostat controlling the fine field adjustment on the follower motor is often sufficient for an entire run of goods, regardless of how frequently the range is stopped, the operator doubtless setting the device to produce a slight tension in the cloth, that is, drag on the lead motor to insure against accumulation of slack. When installing a drive for this sort of a range, particular attention should be given to matching up the motors so as to provide similar speed relationships when inching and starting, as well as when running continuously at higher speeds.

As to multivoltage direct-current systems, the Ward Leonard is at present its principal exponent. It utilizes the common, standard, direct-current, shunt-wound, constant-speed motor, but requires, however, an individual direct-current generator for each range, the speed regulation of motors supplied from this generator being obtained by field rheostatic control of the generator, that is, of the impressed voltage itself. Additional vernier rheostats are furnished with the individual motors to obtain, through dancer-roll equipment, the necessary automatic adjustment of synchronism.

This system is also highly developed, its particular field being plants having only a few ranges requiring but a slight amount of direct current. The control wiring is the simplest of all systems.

The alternating-current adjustable-speed drive with continuous operating ratios of 3:1, or greater, is proprietary equipment. One of the primary advantages of this system is that for a plant already equipped only with alternating current it eliminates the capital expenditure for space, fixed charges, and maintenance and some of the energy losses in equipment necessary to convert alternating current to direct current. It also has the further advantage for plants making their own power, but dependent on purchased alternating current for standby service in case of generator failure, that outside service is immediately available without conversion.

A further recent and comparatively expensive development for automatic control without the use of dancer rolls is known as

the differential regulator or rotary field rheostat. This has been used in paper-mill ranges and for pile fabric which latter would be damaged by dancer rolls. It consists of a continuously adjustable rotary field rheostat driven by a synchronous motor, and mechanically operated by the differential movement of a screw and nut, both of which operate continuously in the same direction, the nut forming a part of the rheostat cylinder, and the screw being driven directly from the section motor.

At the present time a continuous operating-speed range of 4:1 with possible slow-down feature for threading-in seems to be the practical alternating current limit, and all that is usually required. It is accomplished by brush-shifting devices. Contrasted with direct-current systems, it is customary for the automatic individual control of each motor to operate over the whole speed change. That is, the governing of the range is effected only by the control of the lead or master motor, the remaining motors coming into step in sequence, as the brush-shifting devices are actuated in turn by their own dancer-roll control, which latter must have sufficient travel to govern its respective motor over its entire speed ratio. These brush-shifting elements may be designed for mechanical operation, or for pilot-motor actuation. The alternating-current system has become highly developed for range operation in the last few years. For example, in one up-to-the-minute arrangement for a three-motor range drive, the scutcher-mangle drier is driven by a 35-hp. motor; a Tommy Dodd by a 15-hp. motor, and the tenter-drier winder by a 15-hp. motor. The 35-hp. lead motor has a pilot motor for brush shifting controlled by a push-button station at the entering end of the range.

The two 15-hp. motors may be operated singly by "Run," "Jog," and "Stop" buttons, and hand speed control, or in range by pressing an additional "Tandem" button in which case they follow the dancer roll to the exclusion of the other buttons. Speed control of the range may be had from either end as when the operator on the entering end on one floor may wish slower speed for splicing, and the operator on the delivery end on another floor wants speed control of drying.

Comparative prices of the three systems line up about as follows for 4:1 ratios and average size motors. The constant-voltage direct-current system including direct-current generator, but not including the alternating-current motor to drive it, seems to run about the same as alternating-current adjustable-speed motor equipment, and about 10 per cent to 20 per cent higher than the Ward Leonard. If, however, direct-current generator capacity is available, or if, to make the comparison fair, alternating-current generator capacity must be added to the alternating-current system, the constant-voltage system would be cheaper. If, on the other hand, allowance must be made for purchasing a motor to drive the direct-current generator for converting alternating to direct current, the latter system will be penalized.

The comparative over-all efficiencies of the three systems are about as follows based upon usual continuous operating speeds, and neglecting starting or slower speeds which are generally of only short duration. Direct-current variable-speed and direct-current Ward Leonard are about equal, and both about 5 per cent superior to adjustable-speed alternating current, provided that direct current is generated directly in the plant. If, however, alternating current only is generated at the plant and must be converted to direct current through a motor-generator set, the alternating-current installation shows an advantage over direct current of perhaps 12 per cent in power consumption. However, the question of efficiency is of little moment in those finishing plants which make their own power, and which also, at the same time, utilize the extra exhaust steam in process work.

Comparative starting torques of the three systems are about as follows:

The direct-current constant-voltage motor is inherently a constant-horsepower motor, whereas the Ward Leonard and adjustable-speed alternating-current motors are constant-torque motors, a reduction in speed causing a corresponding reduction in horsepower. Consequently, in the two latter cases, special attention must often be given in selection of proper rated horsepower to insure sufficient power at the lower speeds.

The comparative power factors of the three systems obviously work out in favor of direct current if no conversion is necessary. Furthermore, if conversion from alternating to direct current is necessary, there is still a difference of a few per cent in favor of direct current based on the use of an induction motor-generator conversion set. However, the necessity for conversion may offer an advantageous opportunity for power-factor correction by using a synchronous motor with over-excited fields to drive the direct-current generator. This often proves a valuable asset in obtaining additional alternating-current capacity, or a better rate for purchased power, the power factor being notably poor in finishing plants.

Comparative Selectivity. When it is desired to provide for operating portions of the range independently, the Ward Leonard system is obviously inferior to either of the others, as its motors are bound up with the varying voltage of the main generator. One important exception however, which is not of infrequent occurrence, is where it is desired to operate the machine to be cut out at considerably higher speed, such for example as with mangle units. This is accomplished by adding manual field control to the particular motors to be operated separately.

Range drives do not always require much speed adjustment. In some instances, as for example, in two-speed mercerizing tenter ranges (threading and continuous operating speeds), two-speed motors may be used in tandem with or without variators. In other instances where 2:1 or lower speed ratios are required, slip-ring alternating-current motors may work out to advantage, although their series and efficiency characteristics tend to make them unsuitable and unstable.

Class 2 Constant-Speed Motors or Mechanically Driven Shafts

With machines or groups driven from constant-speed sources, it, of course, makes no difference whether these sources are mechanically driven or motor-driven shafts. In either event, the individual groups may be synchronized by means of mechanical speed changers based on various principles, including the use of such well-known devices as expanding pulleys, cone pulleys, variators, and more recently the fluid motor known otherwise as the "oil gear" or "hydraulic variable-speed transmission." The latter type of transmission is comparatively expensive, but has been quite highly developed and very successfully used in the paper-making and in the tire and rubber industries. It does not seem as yet to have been adopted widely in finishing plants.

At the present time the mechanical variator is quite extensively used for converting constant speed to adjustable speed. It operates on the principle of varying pulley diameters, and was first developed for manual control only. It is a competitive device, now highly developed, and used in range drives for the automatic synchronization of various groups. This is accomplished usually through the familiar medium of a dancer roll which operates on the variator directly and mechanically, or which, instead, may actuate the variator through a reversible pilot motor.

Variators have the advantage of being applicable to all types of constant-speed drives, whether motor or mechanically driven. In late years they have been much improved as to general design, including space requirements, and maintenance expense. They are, moreover, subject to somewhat less power losses than for direct current obtained by conversion, especially at slow speeds,

but lack some of the refinements of control found in motor drives. This drive, even more so than the direct-current constant-voltage type, is obviously a constant horsepower proposition as far as the motor is concerned, and has therefore the advantage of high starting torque.

The initial cost of the variators with constant-speed motors as compared with the lowest price system of adjustable-speed motors often shows a slight saving in favor of the former.

Class 3 Adjustable-Speed Small Steam Engines

Small adjustable-speed steam engines in range seem to be infrequently used on account, no doubt, of trouble from oil, dirt, etc. Speed control and synchronizing may be accomplished, however, by manual or automatic control of steam supply through the medium of a dancer roll, as for other types of adjustable-speed equipment.

Perhaps it is fair to consider the field of steam engines in range drives limited to moist places unsuited for electrical control equipment, and where exhaust steam may be used for nearby process work.

Applications

Range drives prove advantageous in many combinations from cloth in the rope form to cloth in open form. Examples of two-unit groups are:

A Open soapers and driers, starch mangles, and driers.
B Mangles and dry cans.
C Dry cans and tenters.

Examples of groups containing more than two units are:

A Bleachery washers, souring, piling.
B Singers, mangles, saturators, kiers.
C Mangles, dry cans, calender.
D Mangles, cold tenter, dry cans, calender.
E Mercerizing ranges consisting of padder, mercerizing frame, double washers, etc.
F Scutcher, water mangle, cylinder, drier, Tommy Dodd, cylinder drier, tenter, cooling cans, atomizer, winder.
G Brusher, mangle, tenter, drier, calender.
H Scutcher, water mangle, drier, starch mangle, dry cans, tenter, and winder.
I Open soapers, cylinder driers, starch mangle, cylinder drier, tenter, cooling cans, atomizer, Simpson winder.
J Alternate choice of starch mangle or Tommy Dodd, cylinder drier, tenter, cooling cans, atomizer, Simpson winder.
K Water mangles, weft straighteners, dry cans, guider, tenter, batcher.

Inherent Characteristics of Range Drives in Finishing Plants

The successful operation of finishing machinery in range is dependent upon the attainment of various advantages, and the relative importance of these items varies widely, according to special operating conditions at different plants and the goods being processed. Each case must be analyzed carefully, and the various factors given their proper weight in the total perspective. Often it is possible to utilize much present plant equipment in reorganized range drives, with little additional machinery.

Some possible advantages of range drives are:

1 *Reduction in or elimination of several "in-between" losses.*

a Economy in man-time is often a major item, and it is not unusual for the installation of a large range to reduce the number of operatives from 8 or 10 men to 2 or 3 men. For example, in the old system, each separate machine might require a man, and some machines two men each, whereas in range, one man might be necessary only at the feed end, one man at the discharge end, and one man for miscellaneous duties, such as taking care of mangle making and trucking.

With regard to smaller ranges, one practical bleacher who is an authority on the subject states that an aniline black installation, for example, consisting of padder, cans, and ager, could easily be operated by two men, especially if equipped with a selvage guider, whereas under the old method, three men would be required full time, and a fourth man for at least half time. Again, if arranged to best advantage, two complete soaper ranges with chrome becks, cans, etc., can be operated by three men. Sometimes placing the units, such as soaper ranges, so as to face each other results in substantial reduction of personnel. Such units might consist of open chrome beck, several rope soaping machines, piler, scutcher, water mangle, guider, cans, and folder. Back gray cleaning can often be done at comparatively small cost in ranges. Such a unit might consist of soaping box, string washers, scrays, scutchers, cans, and batcher. Careful inspection of seams and the use of lap seams made on needle machines should insure continuous operation of the range at from 100 to 150 yd. per min.

b Economy in actual machine time. Some plants allow 20 per cent or more idle time for machines when operated singly, due to transferring, threading, etc., and have found this loss reduced to 5 per cent with range drives.

c Economy in storage space may easily be worked out in the drafting room.

d Economy in cloth time accomplished by keeping the cloth on the move promotes customer satisfaction.

e Economy of cloth, that is less damage to cloth ends. With single machine operation there is often an actual loss of several yards at each separate operation due to threading-in, and dirt from handling in the box or roll form.

2 *Improved uniformity and quality of product* resulting in reduction in seconds. This is due to several reasons, as follows:

a Less narrows, due to less frequent threading-in.

b Keeping fabric straight and square as to weft or filling. This has been a baffling problem with some finishers of wide goods, such as sheetings. Range drives eliminate angularity of pull between separate machines, which angularity often causes expensive losses due to crookedness of cloth.

c Less damages due to stoppages. Fabric processed in properly designed, maintained, and operated ranges is subject to the same treatment throughout. In fact, one authority says that for aniline-black installations the padder, cans, and ager must be put in range to secure best results.

d Less damage to cloth ends is more fully explained in 1 *e*.

e Less likelihood of damage from dripping oil and dirt from overhead shafting, etc., during transportation and storage between machines.

3 *Saving in power and maintenance expense* often results through a carefully engineered straight-run layout, such as the range drive, as compared with the old system consisting of a multiplicity of shafts, belts, pot eyes, quarter turns, etc.

4 *Saving in executive and office work* due to greater simplicity and ease in scheduling and following up progress of goods through the plant.

5 *Increased production* due to the fact that machines may be designed and operated at maximum speeds. This, however, is likely of attainment only if run upon a few staple and similar lines of goods. Otherwise, the reverse is likely to be the case.

There are also inherent disadvantages in range drives which must be overcome as far as possible in order to obtain maximum economy. These, too, vary in number and importance, and should be the subject of thorough investigation for each individual case. The history of range drives is not one of uninterrupted progress, some ranges having been erected and later dismantled on account of inflexible and costly operation. One instance has been brought to the author's attention where it was attempted to

sulphur dye, wash, after treat, dry, finish, dry, and frame in one range. This was overdoing it, and it was found impracticable under the existing conditions at the plant to obtain either uniform shade or finish without frequent stops of the entire range which usually damaged much of the cloth.

Disadvantages of Range Drives

1 *The present market tendency toward a multiplicity of small lots and varied styles, and the demand for samples.* This results in disproportionate expense from set-up costs involving losses in machine and man-time caused, for example, from changes in the "making" for mangles, changing widths and speeds for frames, changing designs, colors, etc., for print machines. One authority states that the average range for vat dyeing cotton piece goods, consisting of padder, four or five wash becks complete with immersion, squeeze, skying rolls, and slip-belt batcher, cannot be economically run on less than 3000-yd. lots. Usually a reduction in the size of range permits reduction in the minimum economical number of yards per run. The above-mentioned market tendency toward small lots may also result in inability to utilize all of the individual units, thus causing idle machine time and consequent increased operating costs. Calenders seem, more frequently, to be driven singly or out of range on account of the many and varied types of calender finishes used.

Arrangement of range drives for selectivity, while adding somewhat to the expense, tends to increase flexibility of operation, and thus may eliminate to a considerable degree the above-mentioned idle machine losses. For example, ranges are often planned with sufficient space between different machines for trucks and boxes and also to include auxiliary folders or winders at these locations. The winder is ordinarily by-passed, but may be used if it is desired to segregate the previous machine. This machine being cut out, the remainder of the range may be used by passing the cloth over and free of it on fixed rollers down to the remaining machinery. With a drive of this sort, variable market demands are not so damaging to production costs.

2 *Range speeds are limited to that of the slowest member* unless selectivity is arranged for. Where tenters or dry cans are concerned this may well be a serious handicap if the weight of goods being processed varies appreciably. That is, unless a standard product can be counted upon, the probabilities are that for a considerable portion of the time, machinery like mangles can be operated at much higher speed. With proper selectivity, however, such machines may be cut out and perhaps operated over one shift where the remainder of the range might be operated continuously night and day. This happens sometimes where tinting is done with the starching.

3 *Breakdowns tie up the production* of the whole equipment besides resulting in damage to the cloth. They are therefore intolerable, and require extra careful and periodic machine inspection and maintenance.

4 *Additional building construction* may be necessary on account of length required, sometimes 200 ft.

5 *Operating losses* due to cloth damage in earlier processes continuing unnecessarily through subsequent processes.

6 *Somewhat greater initial machine expense.* This is largely due to automatic control features, especially if selectivity is required.

Acknowledgment

Grateful acknowledgment is made to the kind interest of various individuals in supplying data based upon their own practical operating experience in charge of finishing plants. These include Harry M. Burke, J. A. Campbell, M. A. Golrick, Jr., G. D. Harrison, Paul A. Merriam, J. D. Robertson, and John G. Shirley.

Discussion

J. A. Campbell.[2] The author mentions that range or in-train drives eliminate the older methods involving intermediate handling, etc., and that they also reduce the personnel. The writer considers these among the great benefits derived from these installations. It is understood that only certain machines can be put in range, and machines when grouped eliminate failure of the human element and considerably reduce the cost of production.

Many plants in other manufacturing lines pay higher wages than textile mills, and where there is a scarcity of skilled labor this industry must use machines wherever possible.

In "Application I" selvage guiders also can be used to advantage, as one of these machines will eliminate one attendant and will pay for itself in from three to nine months, depending upon the type purchased.

In "Application K" this range is used to frame goods for printing, and a batcher with a cutting-off knife can be used. With the common type of batcher the machine will need to be slowed down to cut the goods, but with the cutting-off attachment the machines can be kept running at maximum speed.

Mark A. Golrick, Jr.[3] The author has covered his subject from many angles, and the writer only can emphasize some of the statements and elaborate on others. This subject is of vital importance to most finishing plants, as many are partially range driven, while others are ready to go to extreme limits and be almost entirely range driven.

The statement made by the author that "the question now is how much equipment to place in range, the number of machines being limited by economics rather than by mechanics," might well be a definition of the application of range drives and is of prime importance as the fundamental basis of all range drives, which can be made mechanically perfect enough to include almost the entire finishing process. The limiting factor is to determine exactly what constitutes an economical range, rather than how many machines can be arranged successfully in tandem from the mechanical standpoint of production. This point cannot be overemphasized, and I am glad that the author's closing thought has been on the other side, or the disadvantages, rather than the sometimes overstressed advantages of range drives.

A clear description has been presented on the types of drives and controls for the various systems of either alternating or direct current, mechanical-shaft drives, and steam. This section may well serve as a textbook for any one considering range drives, or even for those who are familiar with certain types which have met their own requirements, but very few have been privileged to experience the complete picture which has been presented here.

In designing a range a few features that may be noted are that special light goods often require a change in machine design, such as the introduction of ball bearnings. The thought must be constantly borne in mind that, with the changes in type of goods to be run, a range may soon be obsolete unless careful planning and forethought provide for its necessary alterations in design. As usual, additional cost is added to the equipment to be installed, but it is generally a paying investment.

Another feature is the growing tendency of cotton converters to handle lighter and high-priced fabrics, requiring the finisher to have better machines than the type that has been used previously on the general run of cotton goods. In this change of style the thought that must be in the mind of the designer of range drives is

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[3] Production Manager, Dutchess Bleachery, Wappingers Falls, N. Y. Jun. A.S.M.E.

that in the case of the substitution of rayon for cotton, particularly on printing machines, there will be required a more powerful drive and, often, a strengthening of certain parts. On the other hand, the lighter goods will require a machine which will run with the minimum of friction, the goods to be kept in almost perfect alignment, and the parts must be rigid and yet offer little resistance to the cloth, which often, of necessity, must drive the roll.

While the author has spoken of the operating features, it is well to note that, in attempting to start operating range drives, another feature that must be carefully considered is the general opposition of foremen, as well as the individual employee, the view being that the new machine cannot do the work equivalent to the old. It is always pointed out by the employee that, with range drives, when one unit breaks down, it holds up the entire process; another point that is emphasized by the employee is the fact that damage or other similar operating fault on a range will be far in excess of that on the original individual machines.

Another feature of operation is that of better lubrication, which is important, as an oil spot may start on a set of cans in tandem with a frame and a batcher, and in range drive the delayed inspection means a greater tendency to extend the fault. Knowing this, the employees and foremen have an argument to support their contention that it is more difficult to inspect range goods, often at higher speeds, than with the former individual machine operation. Of course, this is true, and it must be remembered that range drives require a superior type of employee to operate, a better and more thorough maintenance, and, finally, the supervision and planning of the routing of the material to be run on the range must be done with great foresight.

Individual preference and local conditions vary the types of ranges which one plant or another may consider superior to a competitor's, but the author has carefully considered the factors which tend to make a range drive successful, and also those limiting factors which must, of necessity, control the limits to which any machine can be applied successfully.

In summarizing, it might be said that, with proper cooperation of the employees, the foremen, and the management, range drives are a great success today in finishing-plant work. The plants which are not equipped for range drives either must limit their activities to special work and refrain from general competition or ultimately be driven to range drives of various types or modifications. Often the advantages have been overemphasized in many ways, and only the bright side of the picture has been painted, but this paper has given a presentation by an impartial judge.

Paul A. Merriam.[4] The author has covered the question of range drives in finishing plants most thoroughly. There is one advantage that is gained by the application of the range drive principle that the writer does not recall having been mentioned in the paper. This is the ability to determine and control cloth tension entering between machines or even within a machine. An example of this last advantage is the case of an open soaper for handling rayons or silks, where each nip is driven by its own motor and the speed of each nip is determined by the compensating roll acting on a rheostat between each pair of nips. This of course allows for variation in shrink or stretch and variation in roll sizes, etc., and assures a predetermined tension on the cloth as it progresses through the machine or machines.

The amount of this tension can of course be controlled by the amount to which the compensating roll is weighted or counterweighted.

[4] Chief Engineer, Providence Finishing Company, Providence, R. I. Mem. A.S.M.E.

Jules de Konkoly Thege.[5] The use of adjustable-speed small steam engines for finishing plants does not seem advantageous. Regarding the problem of superheated steam, as used in textile mills, the writer would ask if there is any tendency toward the application of adjustable-speed small steam engines for finishing plants in the textile mills of the United States.

In the writer's experiments in the Hungarian Cotton Manufacturing Co., Ltd., Budapest, the use of this type of steam engine was not profitable. Calculations were made as to whether the operation of the steam engine or the adjustable-speed motor or the constant-speed motor with mechanical variator is cheapest. Finally it was found that to drive the cylinder driers with steam engines is more expensive than with the other machines. By replacing the old adjustable-speed engine by a constant-speed motor with mechanical variator, it would pay for itself in a year. However, when exhaust steam may be used, it makes operating expenses cheaper. The manipulation of a motor, either with adjustable speed or with mechanical variator, is easier. It does not need skilled labor. Other disadvantages in the use of steam engines are the troubles from oil, dirt, etc.

Edwin H. Marble.[6] Lost time seems to have been so closely connected with the human element in any industry that its association with the mechanical element is often lost sight of, yet any efficiency engineer will show you how strong an influence it has upon the two sides of the balance sheet of an organization. With his stop watch he will give you the difference between the operating time and the elapsed time of the mechanical equipment under investigation. How to reduce this mechanical lost time has been given careful study in many processes, and how to operate each machine at its normal rate of production has been the object of many a close investigation. It is one form of research that has paid dividends when properly conducted, and research is one of the best investments in the textile industry.

This research has demonstrated two clearly defined causes of losses in production—first, the loss caused by less than normal output of the machine and, second, and perhaps in many cases the more important from a financial point of view, the poorer quality of a portion of the output caused by the speed reduction.

Discussing the first, on machines giving a nominal output of 100 yards per minute, a stop of two seconds means a loss of $16^2/_3$ yards, with all the other expenses except power remaining the same. In the second case, the stopping of any machine when the fabric is being processed means a difference in quality of the output that is quite serious in most cases. To quote a remark made by an old manufacturer, "If there is any portion of the fabric that is below quality my customer will discover that portion first." With this preliminary, the writer will bring to your attention an example of how a common intermittent operation has been eliminated.

In the singeing of fabrics, any halt in the normal transit of the fabric through the machine causes an unequal quality which is very noticeable. The stopping of the normal rate of travel for any reason not only reduces the production directly in proportion to the length of time the stop occurs, but the regaining of normal speed adds its quota to the proportion of unequal-processed fabric. To make this particular process continuous there has been adopted a sequence of attachments or units.

The fabric has been previously assembled in several loom lengths or cuts, usually amounting to 300 to 500 yards. The normal speed of travel through the singeing machine may be 180 yards per minute. The assembled fabric is unrolled or taken from the truck by an unrolling frame and deposited in a scray or re-

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[6] President, Curtis & Marble Machine Company, Worcester, Mass. Mem. A.S.M.E.

ceptacle capable of holding 2000 to 3000 yards, this unrolling being done at a speed considerably faster than the normal speed of the singeing machine. This increased speed allows time to sew the tail end of the entering piece to the head end of the following piece, with the best type of sewing machine for that purpose being determined by the style or character of the fabric being run.

The singeing machine is usually equipped with two small brushing attachments, one in front to remove any foreign matter and one at the back to clean the fabric of any chaff or burned particles, these three sections being operated as one unit. The fabric is drawn from the scray through the brushing attachment, is singed, again brushed, and is deposited in a second scray back of the second brushing attachment, the fabric being carried along at the normal singeing speed. Back of this second scray is an independently driven unit in the form of a rolling-up section with suitable guiding attachments, being driven by a two-speed motor with the slower of the two speeds arranged to synchronize the speed of rolling with the normal speed of the singeing machine. The second or faster speed is 20 to 25 per cent faster.

From the scray the goods are drawn along to the rolling section at the normal speed until the roll thus built up is as large in diameter or contains as great a yardage as is desired. When this has been accomplished, this unit is stopped, and the goods are allowed to accumulate in the scray. The roll of fabric having been removed, a new shell is inserted, the cloth is started along, but at the faster of the two speeds and drawing from the accumulation in the scray until that accumulation is reduced to a minimum. The speed is then changed to normal until it is necessary to again change the roll.

J. D. Robertson.[7] In the installation of direct-current adjustable-speed range drives one fairly obvious point that sometimes has been overlooked is that the pulley sizes must be so chosen that equal cloth speeds in all units of the range will result from equal motor speeds with the dancer-roll rheostats completely cut out.

For example, if the motors used are 500 to 1500 r.p.m. motors and the desired cloth speed is from 30 to 90 yards per minute, it is necessary in order to get the full range of speed that the pulleys be chosen so that when the cloth is running at, say, 30 yards per minute in all units, all the motors will be running at 500 r.p.m., with all dancer-roll rheostat resistances cut out.

The number of operations to be put in a range and the extent to which range drives can be used to increase profits are largely determined by the number of kinds of work a plant has to handle and the frequency with which the kinds change.

For example, if a concern in a cutting-up trade, such as a shirt maker or a curtain maker, finishes its own goods, it can profitably tie up more money in an elaborate range of operations than a commission finisher handling a large variety of work and subject to all the whims of fashion in a large number of lines, because the cutter-up will be able to use his equipment a much longer time before fashion shall require it to be changed than will the commission finisher.

However, when deciding on the installation of an increased number of operations in range, careful consideration should be given to the difficult-to-estimate, profit-increasing factors involved in any industrial layout tying a number of operations together such as the chain-assembly methods and materials-handling systems first developed so highly by Ford and now generally used throughout the automobile trade and many other metal-working lines. In such cases a considerable investment in material-handling equipment is made in order to eliminate the delays and increased inventory required by handling goods in boxes and trucks. Practically all the advantages of such an investment are available to the cloth finisher merely by carrying the goods from operation to operation in the rope or open width instead of in boxes and by using range drives where necessary.

Henry M. Burke.[8] It has occurred to the writer that one matter might be injected into the discussion, and that is the question of the development of the B.T.A. motor for variable-speed range drives. It is probably not a well-known fact in plants that have not the advantage of direct current that it is rather difficult to secure satisfactory variation in the drive with the alternating-current variable-speed motors that have been built in the past.

Take, for instance, a large vat dye range operated by alternating current: it is quite necessary to stop this range, which is made up of dye pad and a series of six-seven-eight boxes, to take off swatches. It is quite necessary to start in threading it at a very low rate of speed. There may be several hundred yards of cloth in the machine passing through the dye pad and a series of boxes which cause a great deal of trouble when trying to get an absolutely uniform shade where variation in speed occurs. When the machine is stopped, the cloth is permitted to remain in the dye and re-reducing tanks, absorbing more color, so that the cloth in the bath at the time the machine is stopped is to be sacrified on account of its being off shade. This is very important when vat dyes are used, as it becomes a difficult problem to knock down the shade or build up the shade, if that is necessary, when that yardage is subsequently rehandled.

If a machine is not properly designed and free from friction, sometimes the cloth breaks on account of lack of uniformity in the rolls and unequal tension in the various boxes. When the goods break, time is lost in trying to rethread the machine properly, and also unevenness of shade is caused. These losses, if not looked after, are the cause of serious disadvantage on a long range, especially if the lots put through are of the minimum quantity that could be economically dyed on such a long range.

Another disadvantage of range is that it is an expensive unit to build, and if the plant is small and the lots being processed in it are small, the cost of operation becomes less attractive than in a plant, even where these long ranges are being operated on very large lots and more continuously.

When various pieces of equipment are put in range, unless special precautions are taken to have sufficient space between the various units, the individual units become a part of that range and cannot be operated independently. The speed of a long range is determined by its slowest operating unit. This is a disadvantage, because quite frequently and in times of poor business this long range becomes practically inoperative on account of not getting sufficient business to run economically. The small plant with a limited amount of capital is sometimes forced to run units in accordance with the maximum speed, so that if they have several units it becomes more advantageous for them to keep them individually operated than to tie them up in a long range.

Much has been said about the advantages of range drive, but the writer thinks that a careful study of the excellent paper will bring those contemplating range drives to a consideration of the disadvantages and the methods to overcome these disadvantages. Take, for instance, range drives today that are built for certain widths of cloth; should the styles change so that wider fabrics are necessary, this range drive for the narrow fabric becomes obsolete. The obsolescence of such an expensive machine is a very serious matter with a small plant operating with small capital. On the other hand, if a range is built to take the wide cloth, the operating of a wide machine takes more dyestuff and liquor than necessary, and that is a serious handicap.

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[8] General Manager, Dutchess Bleachery, Inc., Wappingers Falls, N. Y. Mem. A.S.M.E.

Therefore, the range drive may be the solution for low costs in one plant and may work out just the opposite in another.

Later on in the discussion, the question arose as to operation of textile machinery with the use of superheated steam. The writer feels that a paper could be presented before the Textile Division that would bring out the advantages and disadvantages of superheated steam in processes. Another subject that is brought up from time to time is the subject of the most advantageous steam pressures. A paper covering this subject would be of great value.

WARREN B. LEWIS.[9] The author has presented the pros and cons of range drives as they apply to the finishing of cotton piece goods in a very impartial and thorough manner and has brought out the basic reason for such drives, which is to reduce manual handling, and the damage resulting therefrom.

As to the method employed, the writer would like to add that about one-half of the power used in a cotton piece-goods finishing plant is essentially of a constant-speed characteristic and one-half is variable speed. If the generating plant is about 50 per cent direct current and 50 per cent alternating current, with a motor-generator set to transfer 20 per cent in either direction, relatively high efficiency of distribution is assured and excellent flexibility of control, from full production to a very low rate.

In such a plant the use of adjustable-speed direct-current motors represents approximately half the power and constant-speed alternating-current motors the other half, assuring relatively high efficiency, a minimum of equipment, and relatively low maintenance expense. Adjustable-speed motors can then be operated in range or the several units be operated independently, as suggested in the paper. Complete alternating-current generation involves either the use of alternating-current or direct-current conversion, with added investment and added losses. This would be justified where a small amount of direct-current power was required, but the case is rather unusual. In such cases constant-speed alternating-current motors with mechanical variators are satisfactory; but frequently the first cost is high, the control far less convenient, and the maintenance objectionable.

The author refers to certain objections in range drives, one being the operation of part of a range at speeds lower than might be possible if operating independently. In most cases this is not economically bad, as elimination of separate handling results in a labor saving in excess of the fixed charge on the machine.

The variable-voltage control has little or no advantage over the adjustable-speed constant-potential system, the former being particularly applicable where very great variations of speed are needed, which is not the case in finishing cotton piece goods. A variable-voltage system multiplies the number of machines in operation, and the total horsepower of electrical equipment is four times that actually applied to the machine.

[9] Consulting Engineer, Providence, R. I. Mem. A.S.M.E.

An interesting and wholly practical arrangement of range drives is in the bleach house, where cloth may be handled continuously from the kier to the white bins through ten machines in range, and yet each one may be used independently or any combination be used independently. Such a range can be made so nearly automatic that labor is reduced to little else than supervision or to straighten out an occasional tangle. Such a range reduces the time in process by days.

The writer believes that he was the first to introduce range drives in the textile industry more than thirty years ago, and utilized a variable-voltage system, today practically extinct, which consisted of six definite voltages produced through a master balancer set and a controller which applied these definite voltages to the motor armatures. For speed controls of as high as 7 to 1 ratio this system was very successful, but the complication of wiring and certain inherent faults in controllers presented disadvantages as compared with the adjustable-speed motor, which was at that time being rapidly improved.

AUTHOR'S CLOSURE

The discussion has certainly proved most interesting and useful in substance and volume, and, together with the unusually large attendance at this meeting, it seems to indicate growing realization that success in the textile industry lies increasingly along the lines of refinement through careful fact finding and analysis.

Mr. Campbell's pertinent remark regarding a further advantage incident to the reduction to personnel, that of eliminating sources of potential human-element failure, is noted. This aspect of the situation resolves itself into human failure versus machine failure, and in some cases it should constitute a partial answer to the difficulty of which Mr. Golrick speaks and which difficulty many have found to be a very real one—that of overcoming the prejudice of operators who are in the habit of pointing out the serious effect of mechanical breakdowns in tying up the productivity of a whole series of machines when in range.

The author also wishes to thank Mr. Merriam for calling attention to the advantage regarding regulating cloth tension. The determination of cloth tension by proper weighting of dancer rolls would, in certain instances, seem undoubtedly to be an additional advantage with range drives.

Answering Mr. Thege's question, and as stated in the paper, trouble from oil, dirt, etc., as well as considerations of fuel consumption, seem to militate against the extensive use in range of adjustable-speed steam engines.

Needless to say, examples of range drives given in the paper are intended only to illustrate certain existing applications and should not be taken as a blanket recommendation for their adoption anywhere without carefully weighing the various disadvantages and advantages applicable to the particular case in mind.

Advances in Control of Plain, Chase, and Schreiner Calenders

By JAMES A. CAMPBELL,[1] GARNERVILLE, N. Y.

A better product from the textile finishing plants has resulted in the past few years, together with greater economies in the processing of goods, as the result of scientific study to obtain the facts. To operate at a profit the modern plant must meet present economic conditions by taking advantage of every opportunity to improve on quality and process. Calendering has become a most important process, as a larger proportion of cotton materials are now so treated; and the paper compares the principles, the designs of machines used, the methods of operation, and amount of production at the present time compared with 1910.



RADICAL advances in the operation of textile finishing plants during the past few years have made it possible to turn out a better product and to realize economies in the processing of goods. The outstanding contributing factors in these advances, i.e., improvement of quality and more economical operation, undoubtedly have been almost entirely made by scientific studies to obtain facts, as very few real facts were generally known in the trade.

The so-called "good results" of the past are not sufficient for the operation of any modern textile plant which expects to operate at a profit. Economic conditions require that advantage be taken of every opportunity continually to improve on present methods, as well as those of the past. Successful plants of today are employing new management methods, which develop initiative in the individual departments. They also continually compare their operations with scientifically possible standards. Specifically, the improvements usually are best handled by separating any problem into its elements. These elements are analyzed for their limitations and interrelations when functioning as a working unit.

As a larger proportion of all kinds of cotton materials are calendered today than in the past, calendering, in its various forms, has become a more important process than ever before in the finishing of cotton goods, and has come in for considerable study, where before it was very much neglected and done in a more or less hit-or-miss fashion, depending upon the ideas of the man in charge of the plant.

This paper will, therefore, compare the principles as well as the design of the machines used, the methods of operation, and amount of production at the present time, with those in 1910, in order to show the tremendous advances that have been made.

The outstanding improvements in calendering have been mostly in actual machine operation, and in improving the design, strength, weight, and methods of driving the machines. There has been, however, no change in the underlying principles of the machines themselves.

From Table 1 a general comparison of the fundamental factors in typical calenders of 1910 and 1928 can be made. Referring to this table it can be seen that:

1 The fundamental principles of the machines are the same

2 Belt-and-clutch drive has been replaced by direct-connected motor drive

3 The average increase in the number of rolls used is two. Modern five-roll heavy calenders with roller bearings usually have a filled roll on the top and bottom. The latest development is to use six rolls having the top and bottom rolls of chilled iron. The latter rolls will last for years, and the same journals are always in the roller bearings. The reverse is the case when filled rolls are used, since they require frequent changing which necessitates equipping all filled rolls in use and spares with hardened-steel sleeves, so that they are interchangeable

4 The increase in diameter of the composition rolls is from 2 in. to 8 in.

5 The increase in diameter of the iron rolls is from 3 in. to 4 in.

TABLE 1 COMPARISON OF TYPICAL CALENDERS OF 1910 AND 1928

	Item	1910	1928
1	Principles of machine itself	Same	Same
2	Method of drive	Belt and clutch	Motor
3	Number of rolls	3 to 4	5 to 6
4	Diameter of composition rolls	18 in.	20 in. to 26 in.
5	Diameter of iron rolls	9 in. to 12 in.	12 in. to 16 in.
6	Width of face of rolls	40 in.	50 in. to 120 in.
7	Bearings	Plain	Roller
8	Pinions	Cast iron	Composition
9	Dampening	Sprinkler (separate operation)	Atomizer attached to calender
10	Expanders	Barrel	3 roll Mycock
11	Roll raising	Hand wheels	Motors
12	Hydraulic pumps	Belted	Direct connected

6 The width of the face of the rolls employed has increased from about 40 in. to 120 in., a majority being about 50 in.

7 Roller bearings are tending to replace plain bearings

8 Composition pinions are generally used in place of cast-iron pinions

9 In the most progressive plants, direct-connected atomizers have replaced the sprinklers, eliminating a separate operation

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Presented at the National Meeting of the Textile Division, Greenville, S. C., Oct. 17, 1928, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

10 Three rolls Mycock expanders are being more and more favored over the barrel type

11 The tendency is to raise the rolls by motors instead of of the old hand-wheel mechanism. Hydraulic pumps operated by hand are also used

12 Plants operating under the most advanced methods are driving the hydraulic pumps by direct connection to the driving shaft.

As the basis of the best operation of any calender is derived from careful time studies, the progressive finishing plant, therefore, has to make numerous checks of all the elements in calendering, so that all unnecessary operations are eliminated, and the machine will be handled in the best possible manner to secure the maximum production with the lowest cost.

Accurate time studies have brought out, of late, the following facts which were only more or less recognized a number of years ago:

1 Calenders which are operated on one side only, require only one operator. On machines where the feed is on one side and the batcher on the other, part time of a helper is required. Large calenders should be installed adjacent to each other, so that one helper can take care of the extra work on two machines. This gives a personnel of $1^1/_2$ men per machine. When only one calender is operating, the helper should receive the same rate as the operator, but when two machines are running, the helper should receive half the earnings of each calender operator. Should a heavy calender be located at a distance, the spare time of the operator can be used to run another machine, such as a sprinkler, paster, or button breaker.

2 The efficiency of the calender operators can be increased greatly if adequate service is provided by the truckers in the department. The truckers should receive a bonus based on the average hourly earnings of the calender operators.

3 The supply of the rolls of cloth should be taken care of so that the operator does not need to leave his machine. Many yards are lost per day through the operator having to move from his machine to get new rolls or wheel away the completed roll.

4 The size of the rolls of cloth must be standardized for different fabric weights.

5 It is important to have shell centers of suitable size and weight, and these must pass freely into the shells so that no time is lost in changing rolls of cloth.

6 Accurate measuring drums should be installed on the machines with clear-figured counters connected to the drums. The counters should be in the line of vision of the operator, and this can easily be arranged by the use of sprockets and chain drives. The gears should be such that the counters directly indicate yardage.

7 Forms for recording the yardage, lot, style, etc., must be designed so that the clerical duties of the operator are reduced to a minimum. The information must be complete. Then accurate records can be made for payment and for cost accumulation. The importance of correctly designed records will be clearly shown by the following. In one instance, it required 1.04 min. for the operator to record the information required on the job card; by rearrangement of this card or form, the time of recording was reduced to 0.30 min. per roll. This change alone added 36 min. per day to the running time.

8 Holders are necessary for the operator's card. These can be installed on the frame of the machine.

9 Calendering operations are satisfactorily compensated by piece-rate payment, the operatives being paid a predetermined rate per 1000 yd. of goods calendered.

10 The installation of piece rates either on straight production or on differential rate, based on increased production, has proved effective for increasing the output. It should be emphasized, however, that the standard upon which such piece-rate payments are based must not be determined in the old-fashioned hit-and-miss manner, but developed scientifically.

11 With judicious rates of payment, the quality of the product is assured.

12 The service time varies slightly. The rates of payment for this time should be computed from the basic hourly rate. As this rate is lower than the piece rate of an efficient worker, there is an incentive to reduce the service time. After the service time is reduced to an apparent minimum, time studies should be made on the complete operation, and standards set for the production of the machine. Table 2 shows typical service, as well as running time per roll.

Table 3 gives a few typical cases which show how scientific study, development of the machine itself, and definite constant control of operating calenders (1) reduces the service time, (2) increases the running time, and (3) increases the yards produced per unit of running time, with consequent reduction in the number of machines necessary to turn out a definite amount of work.

TABLE 2 CALENDER OPERATIONS

Calenders	Yards per minute per machine of	Minutes per roll 800 yd.	Minutes per roll of 1000 yd.	Standard service time in min.	Total standard time per roll of 800 yd.
Plain	100	8	10.00	3.04	11.04
Hydraulic	107	7.47	9.34	2.73	10.20
Chase	127	6.30	7.87	3.91	10.21
Schreiner	25	32.00	40.00	2.36	34.36

A summary of all the facts outlined shows that:

1 Calendering is a scientific process, not an "art."

2 There has been no change in the fundamental principles of the machines.

3 There has been a definite advance in the actual design of the machines.

4 Most machinery was run on beliefs and not facts.

5 Considerable machinery is now being run on facts and not beliefs.

6 The tendency is to substitute continuous for intermittent processing.

7 It is better to replace human guesses or judgment by chemical, physical, and mechanical control.

8 With scientific control, definite schedules can be maintained more closely.

9 With scientific control, the earnings of the operatives have been increased.

10 With scientific control, the cost per yard has been reduced.

It is the opinion of the author, therefore, that:

TABLE 3 COMPARATIVE DATA 1910–1928

Types of calender used	Types of materials calendered	Speeds in yards per minute Actual 1910 Average	1910 High	1928 Low	1928 Average	Difference between 1910 and 1928 average Actual	Per cent	Division of operating time in per cent 1910 Running	1910 Service	1928 Running	1928 Service	Production in yd. per hr. 1910 Actual	1928 Actual	Per cent increase
Plain	Shirtings and dress goods	60	110	110	110	50	83.3	50	50	85	15	1800	5280	193
Plain	Heavy linings	70	180	160	170	100	142.8	50	50	70	30	2100	7140	240
Chase	Shirtings and dress goods	70	135	120	127	57	81.4	50	50	80	20	2100	6096	190
Hydraulic	Dress goods	70	112	100	106	36	51.4	50	50	80	20	2100	5385	156
Hydraulic	Sateens	70	112	100	106	36	51.4	50	50	80	20	2100	5385	156
Schreiner	Dress goods	18	46	23	25	7	38.8	78	22	90	10	540	1350	150

A There will probably be no radical changes in the underlying principles on which the machines operate.

B There will be a more general knowledge of the facts of calendering.

C Operation will be based more and more upon scientific facts and definite control of operation.

D Quantity and quality will increase through better control of (*a*) temperature, (*b*) pressure, (*c*) conditions in which the goods arrive at the calender, (*d*) better methods of handling, (*e*) further experiments should be carried on to run two rolls of cloth at one time on chase calenders, and (*f*) more consideration should be given to mechanical handling of cloth rolls.

TEX-52-4

Theory and Practice in Textile Drying

By B. R. ANDREWS,[1] CAMBRIDGE, MASS.

THE process of coloring and finishing textile fibers is almost without exception carried on while those textiles are wet or become wet by means of the process. This wetting and drying out may occur from two or three times to seven or eight times in the preparation of a single fabric. Therefore, drying is one of the large costs in the manufacture of any textile, and the drier an important manufacturing unit.

The relative values of different driers to any manufacturing plant depend solely upon the relative earning capacities of those driers, and this earning capacity must take into consideration the overall earning capacity of any range of machines of which the drier is a part and in which it is the limiting factor of the capacity of that range.

The cost of operation of a drier alone can be divided into a charge for interest and depreciation of the investment, which must include the proportional floor area occupied by the drier and its appurtenances, as well as the cost of installation, maintenance, labor, power, and steam. Where the drier is one machine in a range of machines, similar charges must be applied to all of the equipment in the range and consideration given to the cost of performing the operation or operations accomplished by the range.

The following tables give the cost of operation in unit production of two very common ranges:

COST IN DOLLARS PER 1000 POUNDS OF DRY STOCK OF BACK WASHING, 52-HOUR WEEK

Pounds of dry stock per hour	Steam and power	Labor	Overhead	Total
100	2.80	3.28	7.85	13.93
200	1.50	1.64	3.97	7.11
300	0.90	1.09	2.62	4.61

COST IN DOLLARS PER MILLION YARDS OF STARCHING AND TENTERING, 52-HOUR WEEK

Yards per week	Av. yd. per min.	Steam and power	Labor	Overhead	Total
62,500	20	265	416	1494	2075
125,000	40	260	208	781	1250
187,000	60	255	139	549	945
250,000	80	250	104	423	779
312,000	100	245	83	354	681

These values are based on 6 per cent interest, depreciation in ten years, labor at $1500 a year for the starching range and $1250 for the back-wash range, steam at 30 cents per 1000 lb., and power at 2 cents per kilowatt-hour.

The speed-of-production limits given in these tables are well within the actual operating conditions in the average plant today, and it is quite evident that those having equipment capable of the higher capacities enjoy a great advantage in the cost of operation over those whose production per unit is still low. The tables are also based upon the assumption that the thermal efficiency of the driers is good; yet this is not a fair assumption, for driers with a high thermal efficiency are almost always those of high capacity, so that the spread between different plants is actually more than the tables indicate. Inasmuch as the figures given show that the importance of production capacity overshadows thermal efficiency to such an extent, an analysis of those points which contribute to maximum capacity should receive first consideration.

A large part of the drying in a textile plant is done on contact driers, such as the well-known dry can. Here the rate of evaporation is directly proportional to the surface of goods in contact and to the temperature of the surface of the can, provided the drying is completed. Therefore, once proper provision has been made to remove water and air from the cylinders, the only engineering in addition necessary to secure maximum practical speeds is to provide a sufficient number of cans.

Other textile-drying operations carried on in heated compartments are subject simultaneously to all the complicated variables of transmission of heat from air to water in the material and those things which contribute to create a difference between the partial pressure of the liquid being evaporated and that of the atmosphere in which it is being dried, all with proper allowance for the interference which substances with a high molecular weight, such as glue, will place in the path of the transference surface.

The capacity of any drier varies directly with the surface of material exposed to the drier atmosphere, so that it is important to see that the holding capacity is the maximum possible without interference with efficiency of heat transfer from drying atmosphere to water in the material being dried. For example, a loop drier should have the longest possible loops with the minimum distance between them.

Many drying operations must be carried on while the goods are being held in machines of a size necessarily limited and the expense of which, both as to first cost and maintenance, is high, such as a cotton or worsted tenter. Here the maximum capacity per unit of goods in the drier is needed, and consideration must be given to those things which give maximum evaporation per unit area and time.

It has been established definitely enough for practical purposes that the rate of drying varies directly with the velocity of the drying atmosphere at the surface of material being dried, where the rate of diffusion from the center to the surface is as rapid as the rate of evaporation. This is the case on such materials as cotton cloth. It is therefore good economy to deliver the drying atmosphere to the cloth in volumes up to the point where the cost of horsepower is greater than the gain from increased production, and so long as the delivery is so uniform that uniform drying is still obtained from edge to edge of the goods.

The variation of drying capacity with temperature is much more complicated. There are two temperatures which must be considered—one at which the drying atmosphere is delivered to the goods, the other that at which it leaves. Up to the point where the drying atmosphere leaves the goods at a temperature only enough above the boiling point of the liquid being evaporated to indicate that the liquid in the material is below the boiling point one rate of evaporation exists, and above this temperature quite a different rate obtains. The whole subject of variation of rate with variation of temperature under either constant or variable conditions of moisture is too large for even a brief discussion in this paper, but it will suffice to say that the rate continues to rise somewhere in the proportion of the wet-bulb depression in the first period, and as the mean temperature difference between drying atmosphere and the goods in the second. Therefore, for maximum capacity it is necessary to have maximum velocity and maximum obtainable and usable temperature,

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Presented at the Northern Textile Meeting, Boston, Mass., May 2, 1930, of The American Society of Mechanical Engineers.

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and from a further analysis of the tables of cost of operation of the starching range it will be noted that the reduction in cost of the operation exceeds the cost of steam within very small limits.

The large amount of steam used for drying makes a careful study of the thermal efficiency of a drier of great importance. The heat supplied may be distributed to evaporation of water, loss by radiation through drier walls, and loss by heating of air entering the drier. The different destinations need to be analyzed separately.

The latent heat of the water evaporated in the drier at atmospheric pressure is greater than the latent heat of the steam condensed at any pressure above zero pounds gage, so that a perfect drier would not be able to show a pound of water evaporated for a pound of steam condensed.

The loss by radiation can be reduced to a very small quantity by well-insulated housings, and while heavy insulation does not show a large return on the investment, in most cases it does produce sufficiently improved working conditions to warrant its installation.

The loss from heating new air is reduced by the use of higher temperatures until it reaches zero at a theoretical exit temperature of 212 deg. This is illustrated by the following table which gives the cost in steam for new air when the exit air from the drier is 25 per cent saturated and outside air is zero:

Temperature exit air	Expended for heating new air in pounds of steam per pound of water evaporated
100	3.38
140	2.00
180	1.26
200	0.93
220	0.84

From this table it is obvious that high thermal efficiency requires high temperature. When this drier temperature is carried still higher, it is quite evident that air is not necessary to the drying operation, for the application of heat is the only thing required for the conversion of a liquid into a vapor. That is, a drier can be built into which the material containing water or other liquid is placed, and into which heat is supplied, and from which only water vapor and dry material are removed.

Inasmuch as such a drier can most conveniently be maintained at atmospheric pressure, the theoretical temperature above which this form of drying takes place is 212 deg. fahr. The actual temperature is, however, somewhat above this. Therefore if a drying atmosphere which is superheated vapor diluted with leakage air is delivered to the material at a temperature of 300 deg. and is taken away at 260 deg., no other new air will be required, and the only expenditure of heat will be for evaporation, radiation, and the small loss caused by leakage.

It is possible to improve the thermal efficiency of can drying by enclosing the stacks in insulated houses so that the exit air may be maintained above the temperature of water vapor at atmospheric pressure, but the gain is apparently less than the cost of obtaining it, so that very little is being done along this line.

While temperatures as high as 300 deg. fahr. are not practicable on worsted cloths, the limits which have gained credence in that industry are much below perfectly practicable drier temperatures, and much higher economies may be had than are general practice in the woolen and worsted finishing.

For those classes of materials where diffusion of moisture to the surface becomes a determining factor it is of no avail to continue to carry surface evaporation to a point of dryness when the center is yet wet. Furthermore, the dry surface in itself becomes an insulator between the heat supply, which is the drying atmosphere, and the wet center. However, heat is the only means by which diffusion can be accelerated without vacuum, so that such materials require driers that are a combination of contact and air drying.

The determination of the relative capacities of different driers is a problem of some difficulty due to varying conditions of wetness both entering and leaving, and an expression of the capacity of a drier must take into account the ratio of water to dry stock, both at entrance and exit from the drier, for it is obvious that a given drier will evaporate a smaller number of pounds of water an hour from a material which is partially dry when it enters the drier than it will from a material which is very wet. Consequently, there is a curve of drying capacity in pounds of water per hour plotted against the ratio of water content to dry goods which is an expression of capacity of any drier, and its capacity can only be expressed by a simultaneous establishment of this ratio.

While the mechanical excellence of the drier is not a theoretical consideration, either of its operation or design, it is a feature which may outweigh the lack of proper recognition and proper application of theory.

A drier is a manufacturing unit. It must handle the goods efficiently without interruption or damage and with the minimum labor both for operation and maintenance. The materials which go into its construction must not deteriorate from vibration or heat. The housing must maintain its insulating value and its ability to prevent air leakage. It should be easily demountable for access to its mechanism or for re-erection in a different location. All bearings and drives must be designed to avoid bearing trouble or oil spots on goods, and all parts should be easily accessible from the inside.

When these considerations of mechanical excellence are combined with the theoretical dictates of efficient and rapid drying, the textile manufacturers and finishers will be operating with equipment that will keep the cost of the operation down to a minimum, and only then.

TEX-52-5

Present Status of Measuring Physical Properties of Textiles

By W. F. EDWARDS,[1] NEW YORK, N. Y.

PROCESSES of manufacturing yarns and fabrics from textile fibers in every part of the earth where silk, cotton, or wool was found were probably known before written recorded history, but there appears to be no record to indicate that the physical properties of these yarns and fabrics were defined up to very recent times. Quality was judged as a result of long experience which was passed along from father to son or from mother to daughter, and became more or less cumulative, and ripened and developed an experienced artisan who was jealous of his art and wished it retained within his family and its descendants as a more or less specialized and secret thing.

There was no motive for a knowledge of physical properties that could not be obtained by organoleptic tests such, for example, as getting a rough idea of strength by tactile and muscular senses, a method of guessing that has come down to the present time. This guessing of strength is of value in the hands of persons experienced in handling light yarns and fabrics for the purpose of roughly indicating relative strengths, but cannot result in safe numerical values. This condition of measuring physical properties of yarns and fabrics may be said without serious error to have continued without much improvement until the beginning of the present century notwithstanding that the processes of manufacturing textile yarns and fabrics had undergone profound changes, especially in regard to machinery and speed.

The two most common motives for measuring quantities or properties are those of detecting fraudulent practices and of determining factors of safety. The latter has been a prominent incentive to measuring physical properties of textile yarns and fabrics so as to give numerical values to the properties in terms of defined units in order that reliable comparisons can be made.

The factor-of-safety motive in the development of standardized tests on textile yarns and fabrics has been the means of developing tensile tests and other strength tests to a point where they may be considered reliable and sufficient for most practical purposes as a measure of the factor of safety of such mechanical fabrics, mostly made from cotton, as are used in the construction of automobile tires; rubber and fabric belting; rubber water, steam, and air hose; and a great variety of rubber goods whose strength is mainly dependent on cotton fabrics; bags for sugar, cement, fertilizers, and various other commercial products requiring bag-like containers; airplane cloth, bolting cloth, balloon cloth, etc.

Interest in this factor of safety became widespread and intense enough so that the American Society for Testing Materials in the year 1915 authorized a standing committee, D-13, on textile materials, notwithstanding that there were probably a majority of the members of the society who were not convinced that textile materials belonged in the scope of the activities of the society, i.e., it was not altogether clear to them that textile materials could be classed as engineering materials. The name of the society does not contain the word "engineering," but its charter states that: "The corporation is formed for the promotion of knowledge of engineering materials and the standardization of specifications and methods of testing."

Committee D-13 was organized at once and devoted its early efforts to the standardization of methods of testing which resulted, in the year 1915, in the publication of tentative general methods for testing cotton fabrics, which included thread count, weight, thickness, strength by both the strip and grab methods, (with illustrations showing how to cut the samples from the fabric), and gave a definition of moisture.

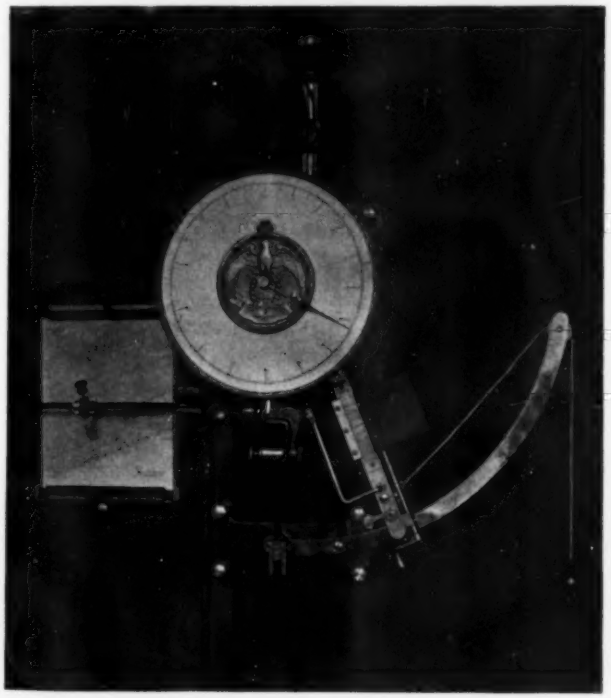


FIG. 1 HEAD, DIAL, RECORDER, AND SLIDING WEIGHT FOR WEIGHING DEVICE

This tentative standard was revised in 1916 and three tentative tests on cotton fabrics used for different purposes were published. The three new tentative tests were: (1) Tentative tests for automobile-tire fabrics, (2) tentative tests for cotton fabrics for use in hose, belting, and similar articles, and (3) tentative tests for cotton fabrics for use in bags and bagging material. These four tentative methods formed a very good starting point for comparisons. Tensile strength comparisons soon discovered many discrepancies that could not be accounted for by any probable variations in the samples used. It was found that samples from the same roll of very excellent fabrics would often give quite different tensile strengths in different laboratories or even in the same laboratory on the same machine.

These discrepancies led to investigations at the Bureau of

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Presented at the Northern Textile Meeting, Boston, Mass., May 2, 1930, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Standards at Washington, D. C., the Massachusetts Institute of Technology, and various other places, and resulted in a number of published reports which in turn led to further investigation and other published reports. It was shown that machines of the same type and different capacities might give discordant results if tests resulted in values coming outside of certain limited ranges of values for two different machines; that speed of separation of jaws on the same machine resulted in different values for the test; that the length of specimen between jaws at starting made a difference in the results obtained; that the moisture content of the specimen affected the results obtained to a very considerable extent; that tests made by the strip method could not be compared with results of the grab method; that tests made by a grab method with one-inch jaws could not be compared with tests

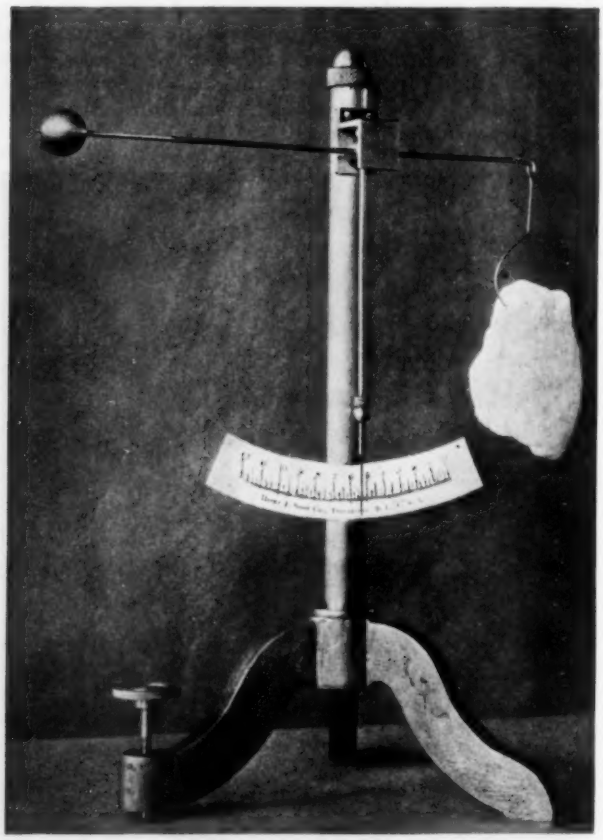


FIG. 2 SAMPLE ON WEIGHING DEVICE

made by the grab method with one- by two-inch jaws, and other less harmful discrepancies were found.

A study of these discrepancies in the tensile-strength tests resulted in the adoption of standard general methods of testing cotton fabrics in 1920, and in a proposed tentative standard specification for textile testing machines also in 1920. The first was adopted after two revisions in 1927 with its name changed to "Standard General Methods of Testing Woven Textile Fabrics." It had been found that the methods used for cotton woven fabrics were quite generally satisfactory for practical purposes when applied to other woven textile fabrics. The second was also adopted in 1927 in a somewhat revised form. Meanwhile, the three tentative tests for cotton fabrics used in automobile tires, in hose and belting, and in bags and bagging material were apparently forgotten, but some twenty or more other standards either as proposed tentative standards or adopted standards had been published embracing a variety of textile materials as indicated by the titles, a few of which follow as illustrative, including two or three published later than 1927: "Standard Specifications for Tolerances and Test Methods," (*a*) for cotton yarns, single and plied, (*b*) for electrical cotton yarns, (*c*) for cotton sewing threads, (*d*) for 23/5/3 carded American tire cord, (*e*) for electrical silk and cotton tapes, (*f*) for asbestos yarns. "Tentative Standard Specifications for Tolerances and Test Methods," (*a*) for rayon, (*b*) for knit goods, (*c*) for Cuban (jute) sugar bags, and (*d*) for asbestos tape for electrical purposes.

These standards and tentative standards indicate that much had been done to give confidence in standardized tests on textile materials, but the practice of using them as a part of the specification in buying and selling contracts was not so general as one could wish. There are several possible partial explanations for the lack of use of these standards, a few of which may be worth brief discussion as throwing light on the present status of measuring physical properties of textiles.

The usual inertia in taking on new ways is doubtless one partial explanation which in this case is emphasized by the fact that many laboratories in the larger units of the industries had been using methods of their own for several years, and had accumulated data that were working out well enough so that naturally there was hesitation to go over to a standardized method the relation of the numerical results of which, to those with which they were familiar, were unknown. How far-reaching this could be is well illustrated by a manufacturer who makes large quantities of a mechanical cotton fabric. He complained that he was selling and manufacturing this fabric to 14 specifications more or less alike, but the relations of which were not well enough known, but that he felt that he must fortify himself by making a portion of the tests for each of the specifications in a somewhat modified way. That the specifications usually involve tensile-strength tests is another quite probable partial explanation of sufficient importance to require further elucidation.

The most troublesome condition of the tensile-strength test on textile yarns and fabrics is the standard moisture condition of the samples at the time of test. This moisture condition must be the same in the buyer and seller laboratories if concordant results are to be obtained. A sample of cotton fabric, for example, tested under ordinary atmospheric conditions on a humid day in a Southern mill in winter may show in the buyer's Chicago laboratory on a cold winter morning a variation of 10 to 40 or even more per cent. The Southern mill laboratory may show a result higher than would be found under the standard moisture condition and the Chicago laboratory might show a result much lower than would be found under standard moisture conditions.

The most common way to produce the standard moisture content is that of exposing the samples from one to four hours, depending on the character of the samples, in a standard atmosphere. The production and maintenance of this standard atmosphere at a reasonable cost in a room large enough to be used as a testing laboratory has been considered by many as prohibitive. Four substitutes have been proposed for the testing room with constant standard atmosphere, but so far no one of them has attained a confidence that has led to its substitution for the test in a room with standard atmosphere for practical purposes.

One substitute method is that of making the tensile-strength test in a comparatively small cabinet in which both the test samples and the testing machine are placed. The operator manipulates the samples and machine by suitable devices from the outside. This method has been perfected to a point such that it is very competent for experimental purposes, but is not practical for mills or laboratories making a large number of routine tests daily.

A second substitute method is that of making the tensile-

strength test on the sample "as is," drying the sample immediately to determine its actual moisture content at the time of the test, and computing by correction formulas the strength of the sample for its condition in equilibrium with the standard atmosphere. Correction formulas have been worked out for a variety of cotton fabrics, but so far do not seem to have gained sufficient following to be brought into general use.

A third substitute method is that of making the tensile tests on all yarns and fabrics in a completely dry state. This seems very simple, but when put into operation it is discovered that it is very difficult to take the dried sample from the drying oven, place it in the jaws of the machine, and make the break without a considerable regain of moisture during the test. It also leads to undue haste in placing the samples in the jaws of the machine which may lead to improper results. A fourth substitute method is that of making the tensile tests on all yarns and fabrics in a completely wet state. This is easy to carry out, but so far there is not enough data to show that it is practical.

Still another partial explanation is the quest for better methods, i.e., more fool-proof or more scientific and accurate methods than those of the proposed standard methods; for example, the variability and magnitude of the stretchiness of textile yarns and fabrics have caused some investigators to go in quest of some better method than the constant speed of separation of jaws because they find that constant speed of separation of jaws is not fool-proof and subject, therefore, to considerable variation. They believe, apparently, that a constant rate of loading is more fool-proof and more scientific in that two fabrics having quite different stretchiness but the same ultimate strength could be brought to the break in the same time by means of a constant-loading device. Some very ingenious devices have been brought out (some with autographic charts) in which a constant flow of water or fine shot constitutes the constant rate of loading. These machines have been used successfully for experimental purposes, but so far the author is not aware of adequate data to show that they are more fool-proof or more scientific than the dead-weight pendulum type of machine with constant rate of separation of jaws as described in the Standards.

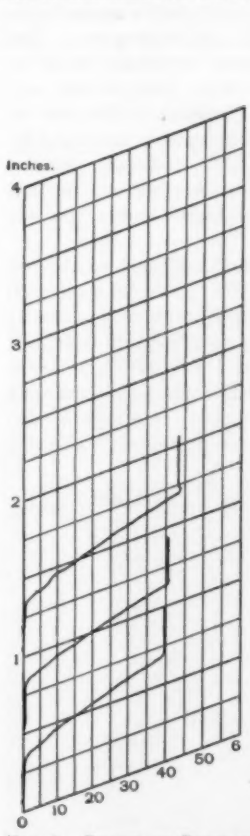


FIG. 3 CHART OF STRETCH IN BREAKING THREE SAMPLES—STRETCH RATIO 4 TO 1

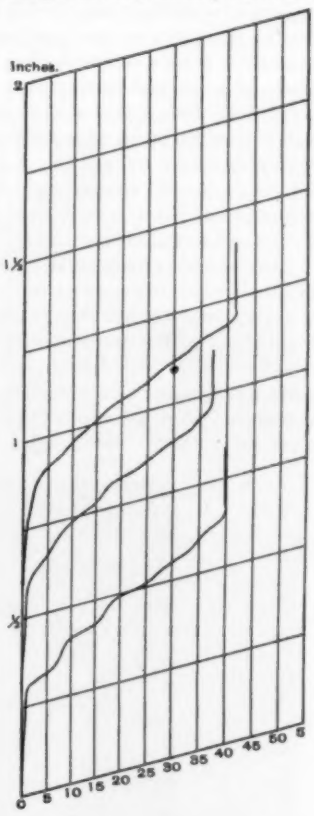


FIG. 4 CHART OF STRETCH WITH RATIO OF 2 TO 1

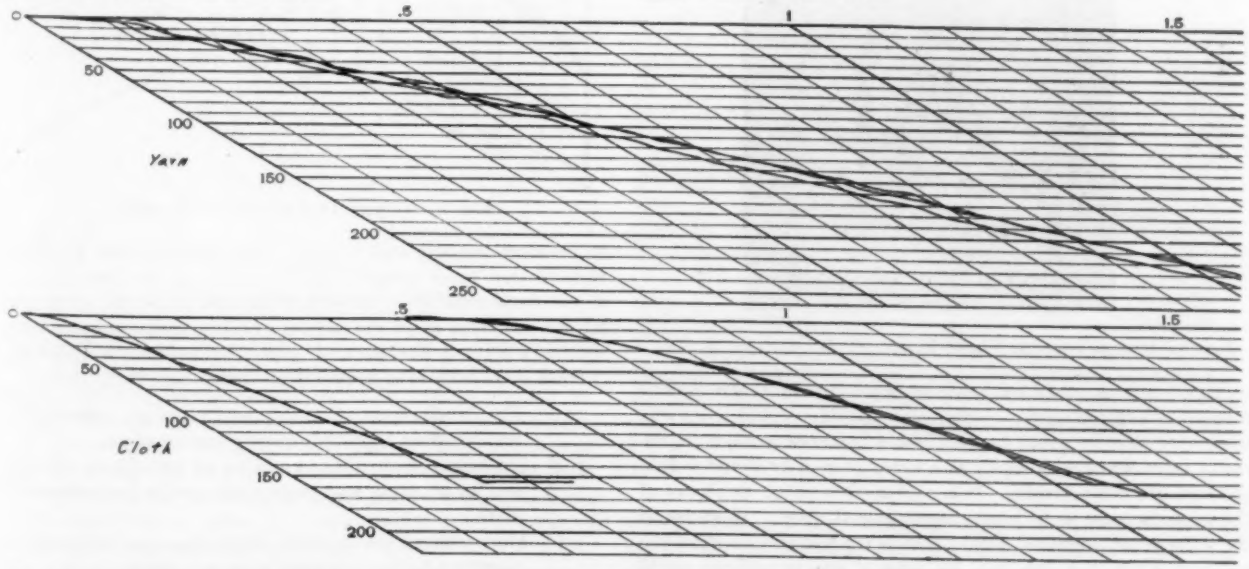


FIG. 5 ABOVE, TEST OF 28 COTTON YARN WITH STRETCH RATIO 10 TO 1—BELOW, TEST OF CLOSE-WOVEN COTTON FABRIC WITH VERY LITTLE STRETCH

Ballistic types of machines have also been proposed, designed, and tried out in a hope of more scientific and more accurate results. The data are not sufficient to warrant an opinion of their value in practical testing. It is desirable always to be looking for more fool-proof and more scientific methods, but such a quest should not stand in the way of using what has already been developed to a worth-while use. The author believes that the deadweight pendulum type of machine has now reached a state of perfection that warrants its very wide use in the textile indus-

tries. The errors due to operator and machine should not be greater than the variations in the materials to be tested or to errors due to the determination of the standard atmosphere.

Lack of confidence may be due also to impossible requirements due to ignorance of the complexity of the requirement. The busy-body groups, of which there is a large oversupply, think in terms of price and performance too much. Performance is a word that often covers a wide range of related factors each of which must be taken separately in the laboratory, and the relation established by continued and wide experience. All are interested in performance tests that are adequate and not too complicated, but the experienced laboratorian knows the difficulty of finding them.

Overconfidence may be as great a stumbling block to the use of standardized tests as lack of confidence. There are some with the very best of intention toward bringing about systematic buying and selling under specification and laboratory tests, but who have more zeal than knowledge, and who have had disappointing experiences due to ignorance and become active retarding influences. A single case will illustrate this. A certain woolen cloth for uniforms was bought on a specification in which too much stress was placed on tensile strength leading to disappointment in the price quoted. Any manufacturer could have told the buyer that he could furnish him a better wearing and generally more serviceable cloth at a lower price if he would reduce the strength requirement. It is perhaps too much to expect of the manufacturer as he might lose a sale thereby. However, if the seller (manufacturer) would always try honestly to show the buyer in a nice but firm way his error, a step in advance could easily be made.

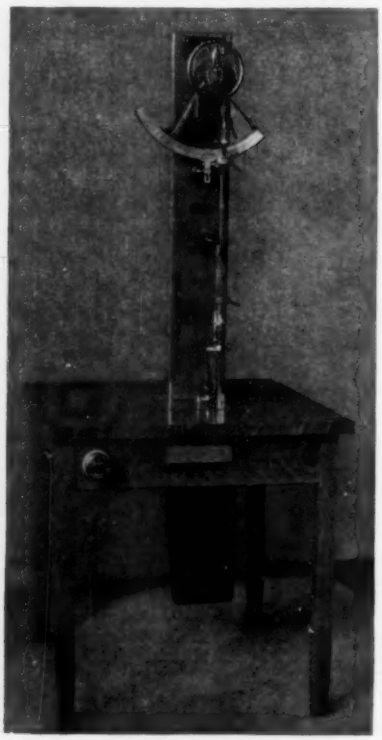


FIG. 6 MOTOR-DRIVEN, TABLE-MODEL SINGLE-STRAND TESTER

The art of the application and interpretation of the results of the measurement of the physical properties of textile yarns, threads, and fabrics with reference to their various uses, is to a great extent in its infancy. There seems to be a rapidly growing understanding that an intelligent try-out in practice is an essential safeguard to every interpretation. It may appear to some that undue emphasis has been placed on tensile-strength tests and standard atmosphere, and determinations of weight, width, thread count, twist in yarns, etc., have been forgotten. This has been done purposely as these latter tests seem to be in a fairly satisfactory state, their moot points in general having been due

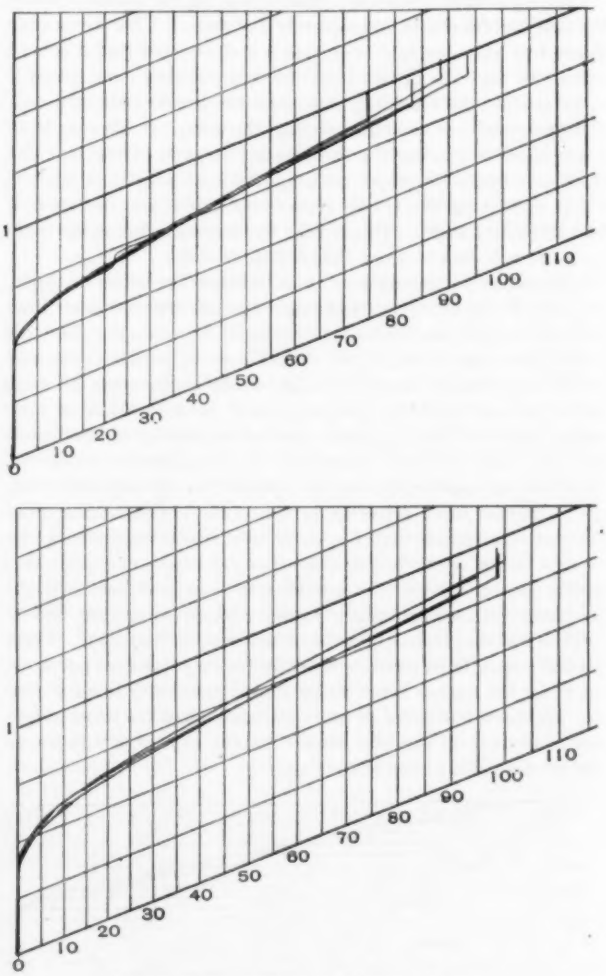


FIG. 7 REPEAT TEST OF MEDIUM FABRIC

to moisture content and stretch. The main purpose has been to show that much progress has been made in the last 15 years in the measurement of physical properties of textile yarns and fabrics, and that all of the ordinary routine measurements have reached a state to warrant their every-day use with confidence.

Some good fields of endeavor in the immediate future are:

- *A* The development of a standard constant temperature and constant relative humidity testing room
- *B* Investigations looking to making all tests in any room in an "as is" state and computing results for a standard state
- *C* More general use of stress-strain diagrams with special reference to their interpretation and use
- *D* Studies to determine the relative merits of the single strand, lea-and-strip tests for the determination of the average strength of yarns
- *E* Further study of the "ballburst" test and the interpretation and application of the results

F Further study of wear tests with reference to standardization of a machine and method of test

G Further study of the folding test, essentially as applied to paper, to determine whether it has a real utility value when applied to fabrics for certain purposes

H Investigations as to the possibility of grading textile fibers by physical measurements independently of organoleptic methods.

The dehumidifying at a reasonable cost has been the most problematical part of the constant-temperature and constant-relative-humidity room up to very recent times. Dehumidifying

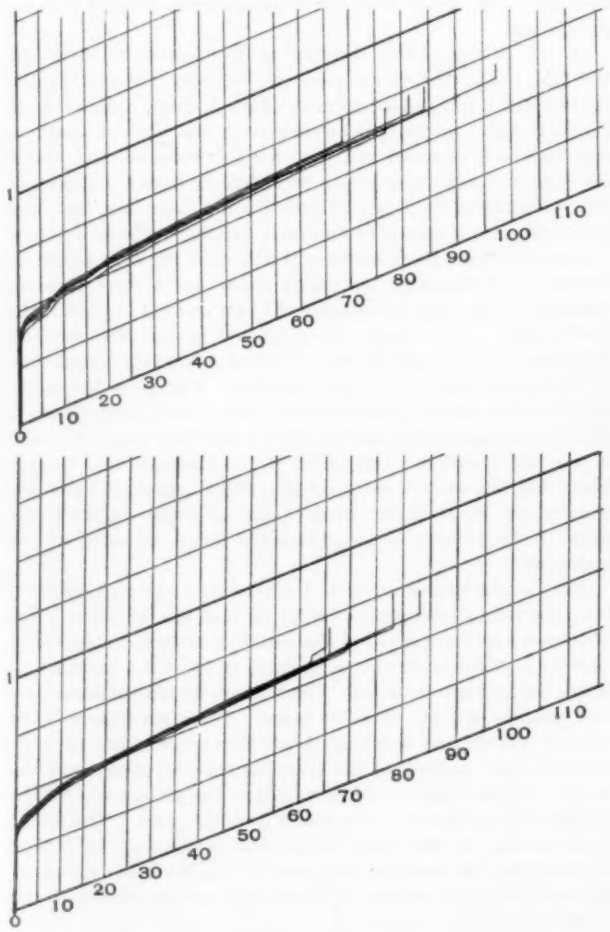


Fig. 8 Repeat Test of Light Fabric

can now be done by use of some of the cooling systems such as are used in meat shops in connection with the humidifying and temperature equipments usually found in laboratories for increasing the humidity and temperature in the winter season, at a reasonable cost for laboratories making large numbers of tests. It is desirable to have a standardized equipment worked out for rooms of various sizes to accommodate a fairly uniform number of workmen. The main requirement for the room is cork-lined walls and properly protected doorways.

The A.S.T.M. standard specification for tolerances and test methods for cotton yarns, single and plied, adopted in 1927, gives a method of determining the tensile strength of the yarn in the "as is" condition and a correction formula for computing the strength under standard conditions. It is based on the experience that regain on these yarns is under ordinary conditions of the atmosphere somewhere between $3^1/_2$ per cent and 7 per cent, the latter being that found for standard atmosphere, and the experience that the tensile strength at any regain up to, say, 10 to 12 per cent is the tensile strength in the dry state increased 6 per cent for each per cent regain found at the time of test.

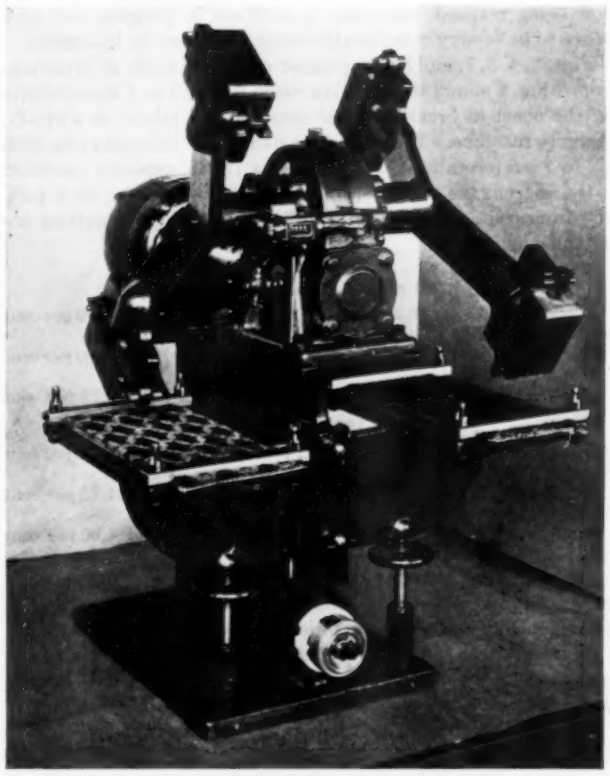


Fig. 9 High-Pile Machine With Samples of a Pile Fabric in Place

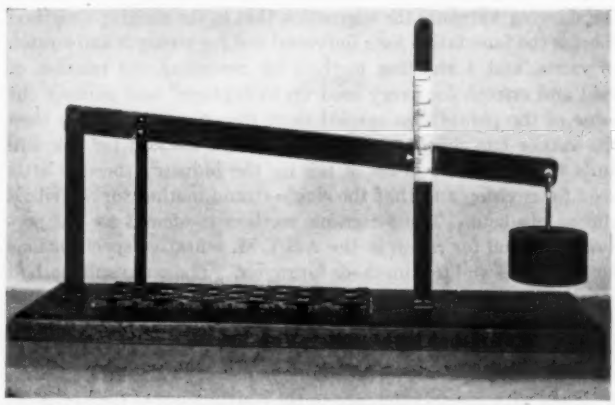


Fig. 10 Device for Setting High-Pile Machine

A machine and regain weighing device are now being placed on the market that do away with the drying operation and furnish the corrected reading directly from the dial of the machine. Fig. 1 shows the head, dial, recorder, and the sliding weight which is set according to the regain of the standard sample shown on the weighing device in Fig. 2. The stress-strain relation in the tensile-strength test on textiles warrants further investigation. From time to time the author has published items accompanied

by stress-strain curves to show that in yarns there is a considerable variation in this relation for different kinds of yarns as well as for different moisture content, twist, etc., in yarns from the same kind of textile fibers. These items and curves have been only suggestive of future work and are in no instance conclusive. The possible value of this relation in both yarns and fabrics is now being realized, and some studies are in progress that may prove to be of very considerable value to the textile industries.

Figs. 3, 4, 5, 7, and 8 may suggest some new fields of investigation. Fig. 3 shows three curves made with a 4 to 1 stretch ratio on the chart in breaking three samples of a fabric on a 110-lb. capacity machine. Fig. 4 shows a like test of three samples with a 2 to 1 stretch ratio on the chart on a 150-lb. capacity machine.

Going from the zero position and from the start to show pull, and from 5 lb. pull to 30 lb. pull in each curve, elongations are obtained as follows:

4 to 1 ratio, 110-lb. machine—Fig. 3

0 to 30-lb. pull....	17.25 per cent, 19.00 per cent, and 17.00 per cent
Start of pull to 30-lb. pull.....	14.00 per cent, 16.50 per cent, and 15.00 per cent
5-lb. pull to 30-lb. pull.....	7.25 per cent, 7.50 per cent, and 6.75 per cent

2 to 1 ratio, 150-lb. machine—Fig. 4

0 to 30-lb. pull....	18.00 per cent, 17.50 per cent, and 17.00 per cent
Start of pull to 30-lb. pull.....	12.00 per cent, 12.00 per cent, and 11.75 per cent
5-lb. pull to 30-lb. pull.....	7.00 per cent, 6.50 per cent, and 7.00 per cent

An analysis of such percentage in enough samples might suggest some changes in weaving, etc., for certain purposes requiring prominence of certain characteristics.

Fig. 5 is a test with a 10-to-1 stretch ratio on a 28 cotton yarn, and on a close-woven cotton fabric with very little stretch. The yarn curves are now shown complete.

At the March meeting of Committee D-13 of the A.S.T.M. in 1926, the author read a paper on a "Universal Tensile Test for Yarns" (published in the April 3, 1926, number of the *Textile World*) in which comparisons were given of a number of tests on silk, wool, cotton, and linen yarns by the single-strand, lea-and strip (serigraph) methods and stated in conclusion, "On the whole, the showing warrants the suggestion that in the serigraph method there is the foundation for a universal test for strength and stretch of yarns, and a charting method for recording the relation of load and stretch for every load up to rupture" and pointed out some of the points that needed more investigation. Since then the author has checked over the serigraph method for silk and finds that after five years of use by the industry there is little need for revision and that the single-strand method for raw silk is almost obsolete. The serigraph method is offered as the preferred method for rayon in the A.S.T.M. tentative specifications for tolerances and test methods for rayon. The serigraph method can be used to advantage for the finer sizes of spun yarns but there are insufficient data to warrant its adoption as a standard for all spun yarns.

An interesting motor-driven table model of single-strand tester, designed with special reference to the convenience of the operator, has recently come on the market. It is a double-capacity machine, 0–2 and 0–10 lb. capacity, and has as novel features, (1) an arrangement of the pointer so that the scale for the capacity used is the only one that can be read; (2) stretch indicator is carried only to point of break; (3) resets for next test by pushing reverse button. It is shown in Fig. 6.

W. H. Whitcomb, chairman of Committee D-13, A.S.T.M., at the March, 1928, meeting of the committee, read a paper on a ball-burst test apparatus which was described as an attachment for the vertical type of inclination-balance strength-testing machine. Data were given to show the probable value of the test in routine and research testing. Since that time further investigations have been carried on which show that a curve showing stress-strain relations may be of value. Figs. 7 and 8 show repeat curves on different samples of the same goods which are remarkably the same though the bursting strength is somewhat different for the different samples. The author understands that the ball-burst test apparatus is soon to be placed on the market as a full-fledged machine to do away with the inconvenience of using it as an attachment.

At the Spring, 1926, meeting of Committee D-13 of the A.S.T.M. the author read a paper on "Wearing Tests on Textile Fabrics which was published in the June 5, 1926, number of the *Textile World*. In this paper were given a few types of machines that had been designed and used for this purpose, and also a description of a machine which had been developed and used in the laboratory of the United States Testing Company, Inc., and gave some data to indicate its value in making comparative tests.

Since that time, Professor Geo. B. Haven of the Massachusetts Institute of Technology has read a paper on "A New Abrasion Machine" at the 1929 fall meeting of Committee D-13, A.S.T.M., at Providence and which was published in the November 2, 1929, issue of the *Textile World*. The paper was very complete as to description and use of the machine. The most important feature in the author's judgment is a device for making the speed of the abrading element uniform over a sufficient length to make it possible to examine the effect of the abrasion over enough fabric that has had the same rubbing effect (speed) to make the examination satisfactory, whereas in the usual reciprocating-stroke method there is no measurable length abraded at the same speed.

Recently the laboratory of the United States Testing Company, Inc., has been developing a carpet or high-pile abrasion tester which has a uniform speed of the abrading surface. A universal machine is planned on the same lines, but so far a satisfactory design has not been obtained. Fig. 9 shows the high-pile machine with samples of a pile fabric in place. The main feature is the circular motion and a spring device for keeping the pressure approximately uniform as the abrading element passes over the fabric. It was found advisable to adjust the platens so that the rubbers worked firmly on the fabric from the start. The device shown in Fig. 10 was finally adopted as satisfactory for setting the machine, the machine being set for the thickness shown on the scale when the pressure of about 30 lb. per sq. in. due to the weight is applied.

There have been a number of devices for determining the power to withstand flexure, such as that of a fabric belt running over pulleys which, like the folding test, are essentially fatigue tests, but so far there is no standardized test for textiles. It seems that there is here a hopeful field for future studies leading to standardized tests. The paper industry has standardized a folding test for certain types of papers. Perhaps the textile industries can profit from its experience.

On the whole, as such undertakings usually go, the textile industries have made a very creditable showing in the last 15 years in the measurement of the physical properties of textiles, and the standardized application of these measures for practical purposes in the industries.

Progress in the Wood Industries

Contributed by the Wood Industries Division

Executive Committee: Wm. Braid White, *Chairman*, Chester L. Babcock, *Secretary*, James S. Mathewson, Thos. D. Perry, and A. S. Kurkjian

SUBSTANTIAL progress throughout American woodworking and wood-using industries may be reported for 1929 in all technical and commercial aspects. Thus, in the field of woodworking machinery we find a still stronger tendency toward the use of individually motorized machines. Moreover electric current as the power source has now become so common a feature of woodworking factories as no longer to call for special comment. This again is leading to the general adoption of a standard of current, in this case alternating, at 60 cycles.

Power

There is also arising a tendency to employ Diesel engines for driving electric generators. Steam plants for generating current are adopting automatic shavings-feeding apparatus for the boilers. Better methods of burning waste wood are coming steadily into use, while at the same time there is a definite tendency to explore the use of what is known as "wood flour" (pulverized wood refuse) for fuel.

In certain plants the idea of sequential operation has been carried out to considerable lengths, especially in the upper Mississippi River district. In cutting departments of sash-and-door and similar plants, conveyor machinery is being installed for handling materials and advancing assemblies.

Short-length lumber is becoming sufficiently important to justify the construction and use of special machinery for using it in manufacture. A foreign-made gang saw has been introduced with some success for cutting small logs which hitherto have been left in the woods owing to the lack of any practical method of dealing with them.

Another interesting new machine is the electric-driven 4-in. molder, which is lighter and more convenient than other machines hitherto commonly used, and which is especially appropriate because of the fact that the greater quantity of all wood molding used is less than 4 in. wide.

Automatic ejectors for use with wood-turning lathes, to eject the finished stock, are being used. High-speed motorized machines are being fitted with automatic electric stopping brakes for cutterheads.

Other electric machinery recently coming into use includes the 2–4-pole motor, or two motors in one, which can be run at extremely high speeds, as high in fact as 9000 r.p.m. with 150-cycle current, and with a minimum speed of 4500 r.p.m.

An automatic clip saw for cross-cutting, which insures greater safety and higher speed, is also coming into use. So is an automatic shaping machine of the rotary-table type. So also is a "wood stamping" machine which simultaneously bores and embosses carved work through a hot-press process. This is being used on plywood work.

Lumber

The grade marking of lumber is becoming a regular practice, and by degrees the consuming trades are coming to demand this additional security, although so far only on softwoods. Hardwood grade marking is being heard of, but is as yet a matter of discussion rather than of practice.

There has been a great increase in the use of "wood flour" for the manufacture of bakelite and similar composite materials. The use of end-matched lumber is undoubtedly increasing. Plywood shows constantly widening uses, in the sash-and-door and the radio-cabinet fields. Radio cabinets have afforded the largest single outlet for plywood construction during the year, and some factories are demanding stock for outputs at the rate of thousands of sets daily.

Research

The search for a perfectly water-resistant glue still goes on. The Forest Products Laboratory of the U. S. Forestry Service continues to do work of the highest grade in this investigation. It has been shown that under certain conditions and within certain limits, animal glue may be made water-resistant to an extent that is useful if not complete.

Researches in the following fields are being actively carried on at the Forest Products Laboratory:

1. Determination and classification of characteristic defects of different wood species from different regions
2. Determination of differences of density in woods of different species
3. Survey of moisture content in softwoods
4. Study of standard measurements of the inflammability of wood to determine the fire-resisting properties of different species
5. Study of better methods of finishing wood
6. Study of the effect of grain direction upon the quality of glued plywood panels
7. Study of the strength of various wood sections, mainly for aeronautical purposes
8. Study of the holding power of various types of nails and screws.

A.S.M.E. Committees

The research committees appointed by the Society at the request of the Wood Industries Division have been carrying on their investigations with fruitful results. The Spark Arrester Research Committee has already made certain practical recommendations as to the design and construction of spark-arresting apparatus for use with steam and internal-combustion engines working in woods and forests. Tests in accordance with these recommendations are to be made on spark-arresting apparatus in the near future, by the Oregon State Agricultural College.

The Research Committee on Saws and Knives has pursued its course. The interest, and to some extent the collaboration, of the manufacturers of saws and machine knives is being secured, and the Committee expects to carry on its work to a fruitful end.

Meanwhile the New York State School of Forestry is giving courses in the utilization of wood. Work is being done on better methods for applying preservatives to wood, and a process of pretreating and finishing wood has been announced which, among other things, will permit the laying of floors ready finished.

Merchandising Study

In general, the whole question of more scientific methods of merchandising lumber, and wood products generally, is being studied. Wood is today compelled to withstand the competition of many materials offered as substitutes for it. The problem of

selling wood products therefore becomes more and more obviously one of scientific preparation and planning. The lumber associations, the societies of manufacturers, and other bodies are giving an attention to these matters which is not the less welcome for having been so long delayed.

Miscellaneous

Among the various interesting activities in the woodworking field may be noted the practice of shipping furniture in plywood boxes instead of in crates; the enormous increase in the use of plywood for the construction of radio cabinets; the gradual but steady transformation of the so-called "sash-and-door" factory into a plant manufacturing all kinds of builders' woodwork; and the general, though gradual, alignment of the wood industries with their younger rivals in their attitude toward the public and toward each other.

The excellent book "Wood Construction," by the Assistant Director of the National Committee on Wood Utilization, Department of Commerce, should be signalized as one of the important features of the year in our field. This is by all odds the best work of its kind which has yet appeared, and should be in the hands of every practical woodworking engineer.

Those, and they are not a few, who still think of the woodworking industries in terms of carpentry and the portable lumber mill, are invited to read the report of fifty years' progress in these industries which forms part of the Society's proceedings for the jubilee year. Today, one may fairly affirm, in machinery, in methods, in accuracy, and in speed, the wood industries can compare favorably with any of the mechanical-engineering branches. It is extremely unfortunate that technical schools and colleges have not long since recognized the evolution of woodworking methods; but for this neglect on their part, which has led to a dearth of trained wood engineers, the industries are themselves mostly to blame. Engineers will tend of course always to go into those fields which show themselves attractive. Only within the last few years has the great importance of wood engineering come to be recognized in any part. For speeding this recognition the Division feels that it may justly claim some credit.

Work of the Division

During the year now past, the Wood Industries Division has been active. Its national meeting at Rockford, Illinois, in October, was the most successful it has yet held. The Division is not unmindful of the fact that, small in numbers as it was and remains, it was the first of the Professional Divisions to hold a national meeting after the decision to allow such meetings had been announced. It has since that time held them regularly each year.

Wood engineering now takes its place as one of the definitely recognized branches of the mechanical-engineering profession. The Wood Industries Division of the Society is pledged to deepen and intensify this recognition. The present writer has been honored by his colleagues with the chairmanship of the Division for four successive years. In retiring from it, at the expiration of his term as a member of the Executive Committee, he believes he can claim to have seen each year a general improvement of woodworking engineering along lines both technical and commercial.

William Braid White, *Chairman.*

Modern Method of Manufacturing Classical Furniture

By HARRY KIMP,[1] LONG ISLAND, NEW YORK

Modern methods of manufacturing classical furniture eliminate nearly all hand operations. They are simplified by the use of the "rod" drawn on basswood to full size, from which measurements are taken by workmen for the construction of each piece of a suit. In this paper the author describes a process for preparing and drying lumber through various machine operations from the start to the completed furniture, preparatory to shipment.

CLASSICAL furniture is a high-grade type decorated to conform with the various style names such as Chippendale, Queen Anne, William and Mary, etc. It is, therefore,



Fig. 1 Cabinet of Ornamented Design

usually special in design and must harmonize with surrounding decorations. In spite of these limitations in some cases it can be made in fairly large quantities. Manufacturing plants for furniture are usually located in congested districts or in large cities since the demand for the product is greatest there. In New York City, there are more plants of this kind than in any other section. In the old days beautiful furniture was hand made, but now mass production has changed matters, and use of modern mechanical equipment eliminates hand work, excepting some hand carving, sanding, and assembly operations.

The personnel of a modern classical-furniture manufacturing plant now includes artisans in design, chemists for wood preparation and finishing, machine mechanics, cabinet makers, hand carvers, veneer laminators, competent production engineers for systemizing the highly developed productive machinery, and others.

As many of the designs (Fig. 1) include ornamentation that cannot be dimensioned on drawings conveniently, it is the practice to draw the designs to full scale on thin basswood. These sheets are called rods and usually include three compact diagrams to show the piece in plan, side elevation, and end views. The rod is thus a long narrow board with the design drawn in pencil, after which it is shellacked.

Fig. 2 shows such a rod. The designs are sketched to full scale by designers and draftsmen to determine the relative proportions and intricate details of the design. They include turnings, carved ornamentation, profiles of moldings, etc. Drawings of this type also include the complete interior assembly or construction of the entire individual design.

Basswood is used instead of paper for the material on which designs are made. Paper expands and contracts with varying weather conditions, and since dimensions are scaled directly from the rod accurate measurements are essential. Paper also has the disadvantages of tearing, the lines disappear with use, and handling operations are more difficult. Information is given to

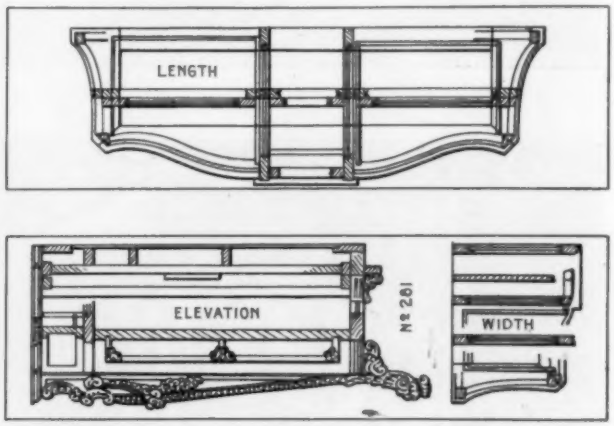


Fig. 2 The "Rod" Is a Board With Design Drawn in Pencil

the cutting department by means of stock sheets. These have a complete listing of material and sizes as obtained from the rod. The stock sheet accompanies cut stock through the machine departments; in some instances the information is transferred to stock tags, blue prints, or similar forms.

Lumber is unloaded from freight cars on to dry-kiln trucks, which pass through a steam-heated kiln, to reduce the moisture content to approximately 5 per cent. This is an important factor for producing workable material. Dried lumber is taken from the kiln into temper rooms where it gradually reaches normal temperatures. In the larger plants lumber lifts are used to facilitate handling. The stock is first cut on a cut-off saw to approximate lengths as listed on the stock sheets. It is then ripped on a chain-feed straight-line rip saw (Fig. 3) which cuts out defects and in the same operation makes the joint for gluing as used for cores, for veneered panels, and in some cases for solid tops. In some cases where the stock is long, it becomes twisted in drying. Then if used for library-table tops, etc., a tongue-and-groove joint is made to insure proper alignment, and to obtain the maximum finished thickness. As very few long tops are made the in-

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[1] Designer, Chesterfield Furniture Company.

Contributed by the Wood Industries Division and presented at the Annual Meeting, New York, N. Y., Dec. 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

stallation of a continuous-feed glue jointer is not warranted so the jointing operation is usually performed on a hand jointer.

In a modern plant with good dry kilns stock is dried straight, and when cut in lengths of 5 ft. and less, it is not necessary to face it on a jointer feeder. After the cores have been glued in a clamp carrier (Fig. 4) they are run through a jointer feeder (Fig. 5) to remove the glue, and take out wind preparatory to the finished surface-planing operation which reduces them to the required thickness.

The beautifully figured veneer used in classical furniture is very expensive. It is cut from flitch stock by veneer cutters to about 0.28 in. in thickness, and when received by the furniture manufacturer contains from 10 to 12 per cent moisture which must be reduced slowly by a veneer re-dryer (Fig. 6) to about 5 per cent to prevent cracking or splitting. This veneer is matched and cut on a veneer cutter which is the same type of machine used for paper cutting. The matched pieces are then drawn very closely together, and are taped by a veneer taping machine which makes perfect joints.

Animal or hot glue is mixed in a container. This drains into a glue spreader which consists of two rollers rotating in a reservoir of glue. The face veneer is not run through these rollers, but the under-veneer or cross-banding which is usually of rotary-cut poplar is glued on both sides by the rollers, and this eliminates the necessity of gluing either the face veneer or the core. One or several cores, with cross-banding and veneer applied are placed in a heavy hydraulic press which eliminates all surplus glue and air pockets, and causes the glue to adhere perfectly. The panels remain in the press long enough for the glue to set, and then they are removed and placed in a dry room where the moisture absorbed by gluing is removed. They are then taken out and trimmed to finished size.

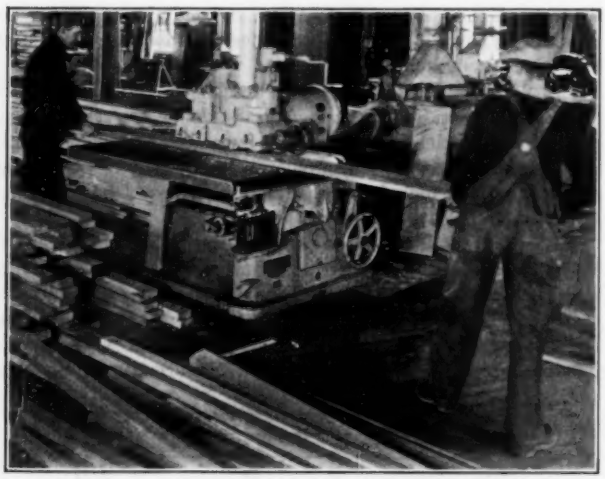


FIG. 3 MOTOR-DRIVEN CHAIN-FEED RIP SAW

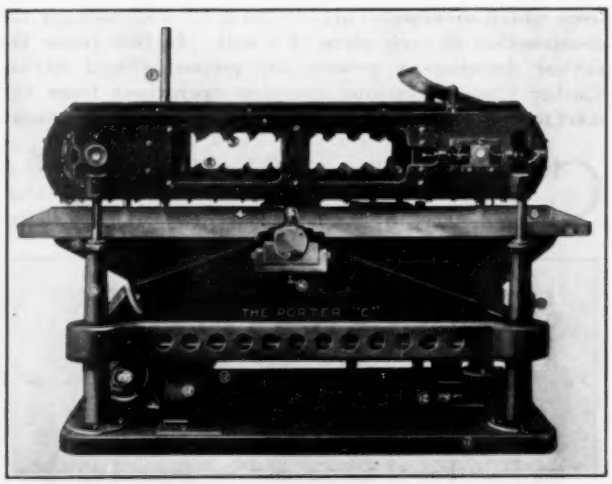


FIG. 5 PORTER TYPE CM FACING PLANER

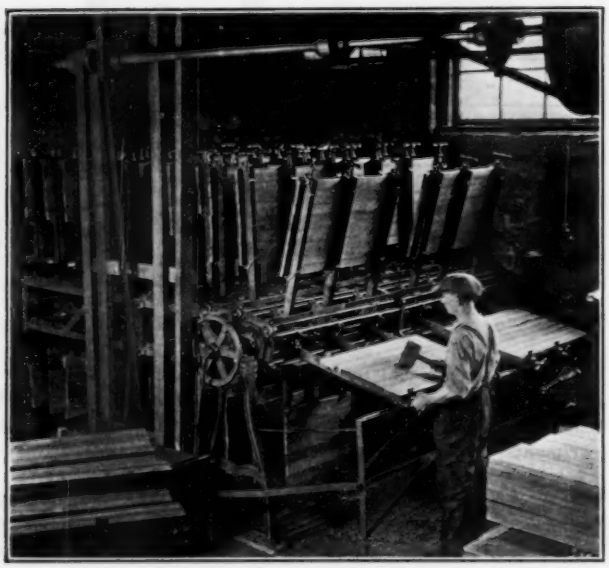


FIG. 4 GLUE-CLAMP CARRIER WITH TWENTY-NINE SECTIONS



FIG. 6 CONTINUOUS-ROLLER VENEER RE-DRYER

Band saws (Fig. 7) are used for sawing the irregular shapes of which there are many, and double-spindle shapers (Fig. 9) are used for molding these irregular shapes. On this type of furniture with its irregular shapes, there are no mortise-and-tenon joints as dowels are used to better advantage. Therefore, both horizontal and vertical single- and multiple-boring machines are used.

Most of the legs for this furniture are polygonal in shape and the automatic shaping lathe (Fig. 8) is used. This machine has cutters revolving at 3000 r.p.m. in approximately a 14-in. circle while the stock to be shaped or turned revolves very slowly. This

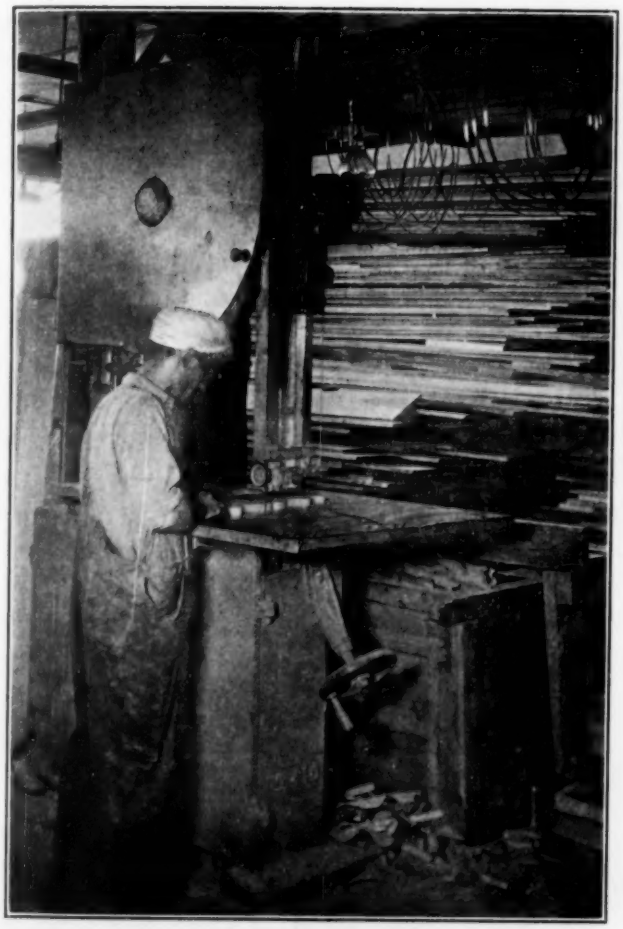


FIG. 7 BAND SAWS ARE USED FOR CUTTING IRREGULAR SHAPES

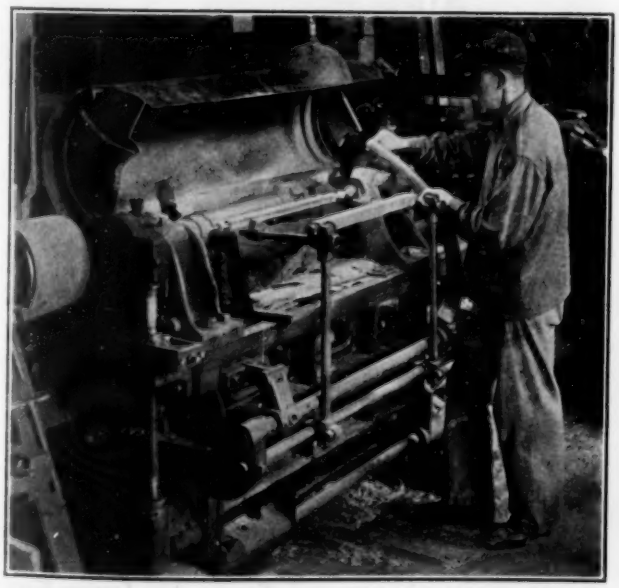


FIG. 8 AUTOMATIC SHAPING LATHE

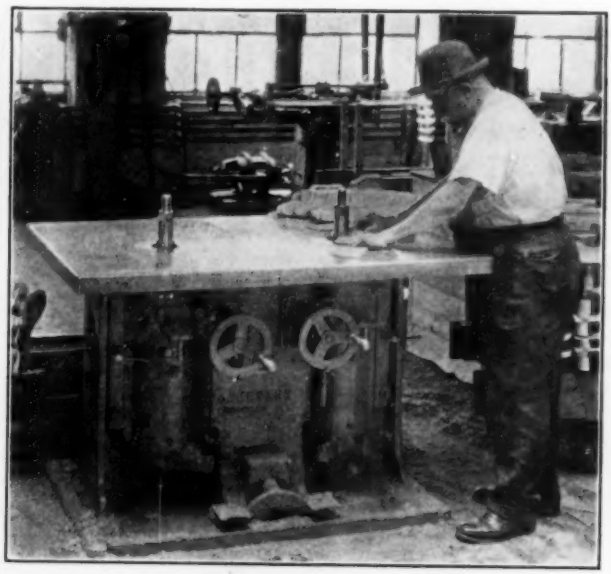


FIG. 9 ELECTRIC DOUBLE-SPINDLE SHAPER

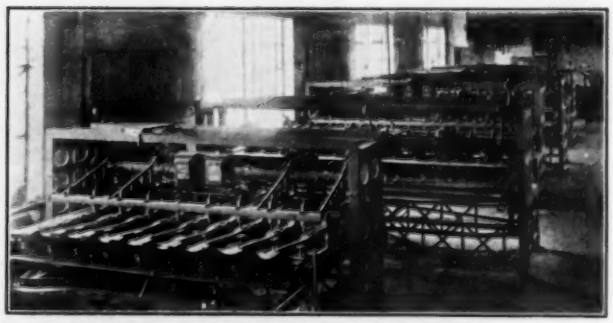


FIG. 10 BANK OF CARVING MACHINES

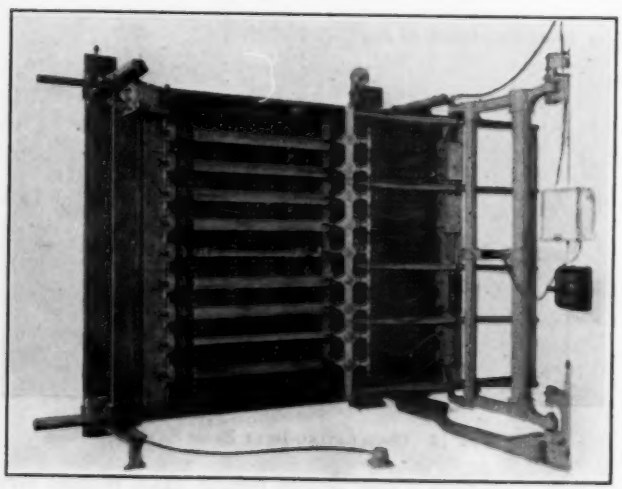


FIG. 11 MODEL NO. 49 CURTIS CARVING MACHINE

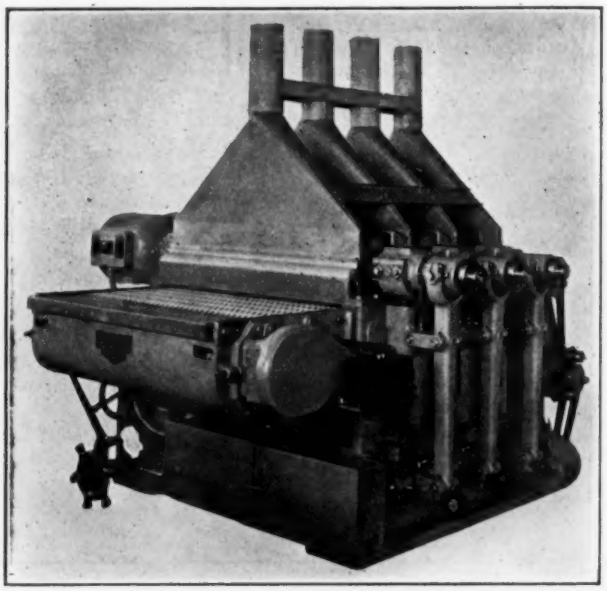


FIG. 12 TRIPLE-DRUM ENDLESS-BELT SANDER

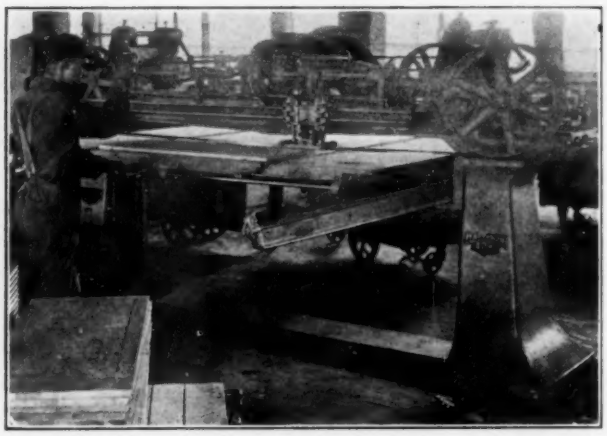


FIG. 13 AUTOMATIC POWER AND HAND-STROKE BELT SANDER

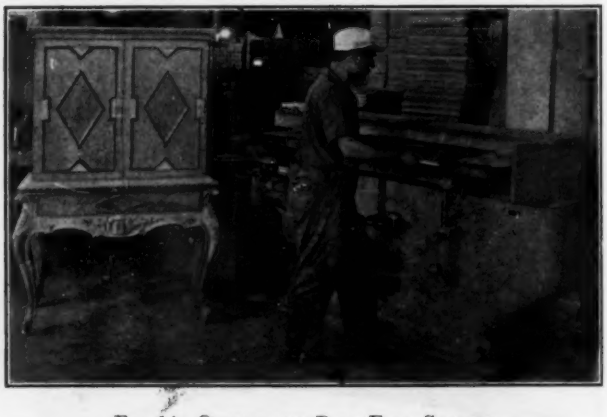


FIG. 14 OSCILLATING-BELT EDGE SANDER

operation produces a very smooth turning which requires very little sanding. Practically all drawers are dovetailed together as no other lock joint is as satisfactory or as simple to manufacture on this class of furniture.

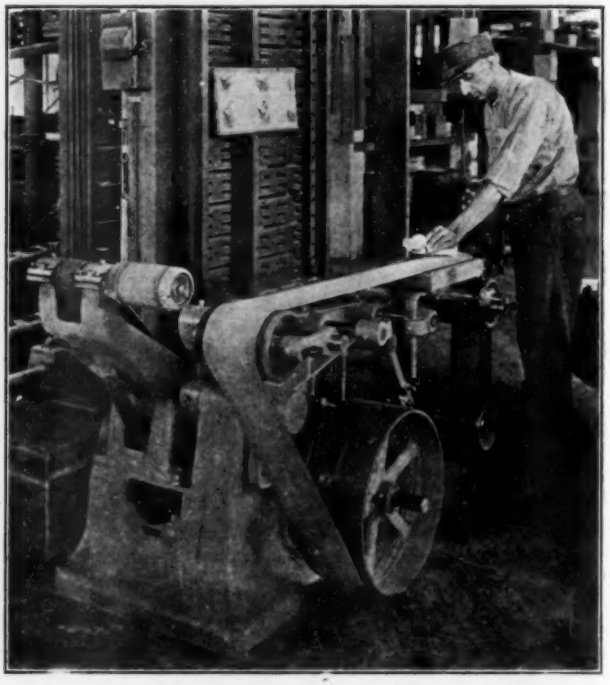


FIG. 15 VARIETY BELT SANDER

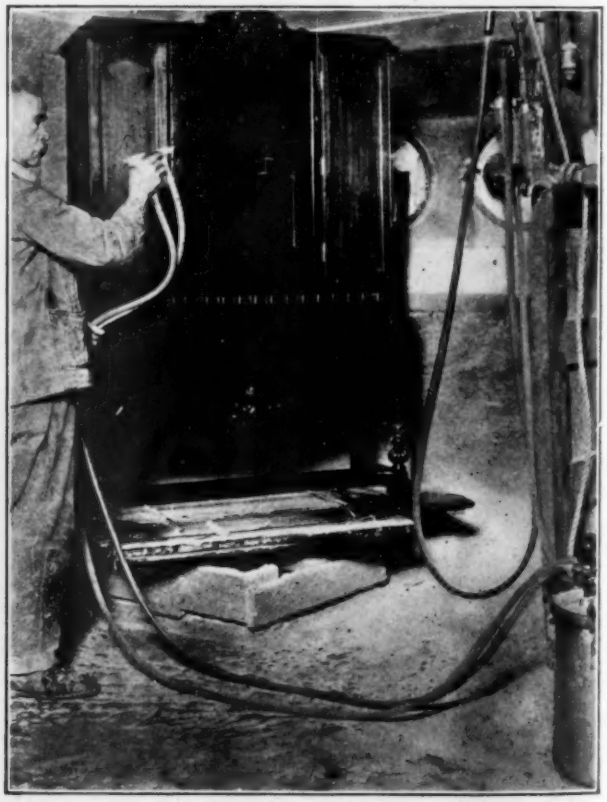


FIG. 16 SHELLAC, LACQUER, AND VARNISH ARE APPLIED WITH SPRAYING EQUIPMENT

Nearly all of the large amount of carving required is done on carving machines (Figs. 10 and 11). The first piece which serves as a model must be hand carved. Several blanks are clamped in a carving machine at the same time, sometimes as many as twenty-four. There is a tool over each piece being carved, and all are directed from a central point where the operator moves a small guiding pin over the hand-carved model. This machine makes complicated carvings in quantities a very simple operation. Some of the intricate carved parts are sanded by hand, but aside from these, practically everything is machine sanded. Small flat parts and flat panels are run through the triple-drum endless-bed sander (Fig. 12), the tape is removed, and a good smooth surface is obtained.

To insure a perfectly smooth panel, however, with no waves, it is necessary to finish sanding them on an automatic stroke sander (Fig. 13). The oscillating-belt edge sander (Fig. 14) is used for sanding straight as well as curved edges. The variety belt sander (Fig. 15) consists of two small pneumatic sanding drums and an endless sand belt which can be operated vertically and horizontally. It typifies its name as it will sand nearly every small piece or furniture part, whether shaped or straight.

The assembling of pieces of classical furniture is practically all done by hand, for owing to the small quantities and irregular shapes, suitable furniture clamps with sufficient range cannot be obtained. In the finishing, much care and attention must be devoted to obtaining the proper color, and therefore each piece is first stained and then all pores are filled. A fine hand sanding then eliminates all raised grain. This is followed by shellacking with a spraying machine (Fig. 16).

Another light sanding is succeeded by one or more coats of either lacquer or varnish, depending on the finish required. This application being dried, the flat surfaces are rubbed with rubbing machines, and irregular surfaces are rubbed by hand with either oil or water and pumice to provide a glossy finish, after which they are allowed to dry thoroughly. The addition of doors, handles, glass, and other fittings completes the work. Although classical furniture is distinctive and individual in design, very little hand work is required in producing it, and modern mechanical equipment is extensively and profitably used, even in the smallest plants.

WDI-52-3

From the Master Cabinetmakers to Woodworking Machinery

The Medieval Carpenter-Furniture Maker—The English Master Cabinetmakers—The French Influence—Materials and Processes—Early Hand Tools—The New Era—Bentham's Planer and His Comprehensive Patent—The Newberry Bandsaw

By J. D. WALLACE[1] and MARGARET S. WALLACE,[2] CHICAGO, ILL.

THE history of woodworking machinery from earliest times until today may be likened to a great and complex drama of interwoven comedy and tragedy. The action opens when the first man uses a block of wood for a seat; the plot and subplots develop steadily through the Middle Ages, reaching a climax in the great industrial revolution of the eighteenth century; the conclusion is modern industrialism with its power machinery and mass production. The tragic moment—if one wishes to call it that—is the passing of the great English cabinetmakers.

Until about 1716 in England most work was purely manual. Machines were not used because they had not been invented. Mass production, industrialism, and capitalistic organization were unknown. The prevalent form of industrial organization was the guild, wherein master worked with his men; and men, in due course of time, all became masters.

The Carpenter-Furniture Maker

Throughout medieval times the carpenter exercised all the functions of joiner and cabinetmaker as well as those of his own trade, for there were no specialists in those days. The carpenter who built a house made all the furniture as well; there was no one else to do it. This method was much more practicable in medieval times than it would be now, because the furniture of that time was very rude and very scant. Plain benches or stools without backs, tables, chests, and beds were practically the only articles of furniture available, even in the homes of the nobles. Those were the days when bathtubs were unknown; when floors were covered with rushes; when all the scraps from dinner were thrown under the table to the dogs. In the houses of peasants, manners were cruder and pieces of furniture fewer than in the homes of the aristocracy.

As time went on, carpenters became interested in making their work ornamental as well as useful. In the thirteenth century the introduction of Gothic architecture into England stimulated the carving of furniture. The relation between styles of architecture and of furniture has always been close. Finally civilization reached the point when men no longer wore their heavy armor while spending an evening at home. Furniture at once could be made lighter. A bench with dainty legs would be comparatively safe for an unarmed man to sit on, whereas it would undoubtedly have collapsed in splintered destruction under a full suit of mail. In the time of James I, the early fourteen hundreds, when the exquisite gentleman arrayed himself in a stuffed and padded jerkin, trunk-hosen, and doublet, furniture was stuffed and padded to match, and made increasingly elaborate.

During the first part of the seventeenth century, oak could be obtained very cheaply, for forests of oak planted by the preceding generations were coming to maturity. This gave an additional impetus to furniture making, and new pieces of furniture were added. Politics and religion had a share in furniture styles also. After the restoration of gay Charles II at the end of the seventeenth century, great popularity was given to the day bed, or sofa, a piece of furniture which the Puritans had eschewed with horror, considering it nothing short of indecent to recline in public.



Fig. 1 Chair by Chippendale, Mahogany, in the Gothic Manner
(Courtesy of Furniture Publishing Corporation Jamestown, N. Y.)

With the increasing complexity of furniture, the trade passed from the hands of carpenters to a group of more specialized workmen. Thus in the eighteenth century came the zenith of individuality in the art of furniture making. Never before or since has the world produced at one time the like of the great English cabinetmakers.

The Master Cabinetmakers

Until the time of Chippendale, furniture took its style name from its period—such as Tudor, or Jacobean, and not from its maker. Thomas Chippendale, who was born in the early seventeen hundreds and died in 1779, was the first cabinetmaker to stamp his own personality upon his products. The man had a good eye for advertising and salesmanship as well as talent in furniture making. His book "The Gentleman & Cabinet Makers Directory," was the earliest of its kind. Chippendale's special skill was in the making of chairs, though he possessed astonishing versatility. Carving was his favorite form of decoration, and he indulged this taste lavishly on his furniture—much of it mahogany, an admirable medium for this style of ornamentation. (See Fig. 1.)

The four brothers Adam (the Adelphi), outstanding figures from 1762 to 1792, were architects as well as designers of furniture, and both houses and furniture designed by them showed the same simple, classic influence. Two of the four brothers, Robert and James, really made the family name famous in the furniture trade. They were designers, not craftsmen, and their commissions were executed by Chippendale, Heppelwhite, and Sheraton,

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Contributed by the Wood Industries Division and presented at the Annual Meeting, New York, December 2 to 6, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.



FIG. 2 ADAM SIDEBOARD WITH PEDESTALS AND KNIFE URNS, EXECUTED IN MAHOGANY, SHOWS CLASSIC STYLE, STRAIGHT LINES, AND RESTRAINED ORNAMENTATION
(By courtesy of Westing, Evans and Egmore, Philadelphia, Pa.)

as well as by workmen of their own employment. The Adam style was a strictly classical one, employing straight lines, restrained ornament, and beautiful painting and inlaying of rare woods. This was in distinct contrast to the florid, curvilinear styles of previous years. Being architects, the brothers did their finest work on cabinets, and it is for these that they are best noted. (See Fig. 2.)

A sort of halfway mark between the brothers Adam and Sheraton is found in Heppelwhite, whose designs, outlasting his life, were most popular from 1765 to 1769. Heppelwhite used curved lines more than the brothers Adam, being much influenced by the French Louis Seize style. He employed light woods, and was partial to painting and inlaying. His articles, particularly the chairs, showed, in spite of their lightness, the sturdier build typical of English furniture. (See Fig. 3.) Heppelwhite's styles were given much notice by the posthumous publication of his two books of design: "The Cabinet Maker and Upholsterer's Guide" and "The Cabinet Makers' London Book of Prices and Designs of Cabinet Work."

Furniture designers of the last decade of the eighteenth century were dominated and guided by Thomas Sheraton. He was more a designer than a craftsman, though he was skilled in all the details of furniture making. Many of his designs reflect the style of French furniture, particularly that of Louis Seize type. Sheraton employed straight lines, graceful contours, and much inlaying and marqueterie. (See Fig. 4.) He was a classicist, but also foreshadowed the modern employment of geometrical designs for ornament. His ingenuity in the invention of double-purpose furniture is very interesting. Commodes and wash-hand stands, in a period when modern conveniences were lacking, were developed into pieces of furniture—"used in genteel bedrooms, and were sometimes finished in a style a little elevated above their use," as Sheraton puts it. A desk is cleverly contrived so that a drawing board on it may be raised and lowered, and tilted to any angle; a Pembroke table (see Fig. 5) is fitted with a shelf ladder folding into its drawer. These and other pieces of furniture make interesting his remarkable book of designs, "The Cabinet Maker and Upholsterer's Drawing Book—the Whole Embellished with 122 Elegant Copper Plates." It may be said that furniture-design books of that century were all, excepting that of the brothers Adam, the work of practical cabinetmakers.



FIG. 3 CHAIR BY HEPPELWHITE, WITH CHARACTERISTIC BACK SHAPE
(Courtesy of Furniture Publishing Corporation, Jamestown, N. Y.)

The French Influence

Throughout the eighteenth century English cabinetmakers derived inspiration from the French, the three noteworthy styles of French furniture at that time being the Louis Quatorze, from 1643 to 1715; the Louis Quinze, from 1715 to 1774; and the Louis Seize, from 1774 to 1793. The Louis Quatorze style (see Fig. 6) was rectilinear, but gorgeously ornamented to fit the character of the "Roi Soleil," as he was called. The Louis Quinze style (see Fig. 7) was more graceful and much less formal, employing a florid, curvilinear structure. A reversion to classicism, extreme lightness and elegance, and the continued use of gorgeous upholstering fabrics characterized the elegant Louis Seize furniture. (See Fig. 8.) Under Louis XIV a very popular form of decoration was Boulle work, an inlay of tortoise shell and metal over a ground of painted wood. Chippendale and Sheraton in particular were influenced by the French, but these English designers Anglicized, as well as copied, the French ideas, so that the product was truly English.



Fig. 4 Sheraton Card Table, Mahogany Inlaid With Satinwood
(By courtesy of Furniture Publishing Corporation.)

Practically all the work of these great cabinetmakers was executed by hand tools, the total output of each designer being comparatively small. It was not until the very end of the eighteenth century, when the time of the great masters was almost ended, that power woodworking machines were invented, and it was still later before they were commonly used.

Materials and Processes

In spite of the handicaps imposed on them by the lack of machinery, the master cabinetmakers were eminently skilled in many processes. Carving, turning, gilding, lacquering, veneering, painting, japanning, inlaying, marqueterie, and fretting were used during the eighteenth century. Veneering, practiced in early times by the Greeks, had been rediscovered in the Middle Ages by Filippo Brunelleschi, an Italian. In 1565 the first veneer mill was set up at Augsburg in Germany by a man named Renner.

Varnish mixed with oil had begun to be used in the sixteenth century, while a manufactory of varnishes—in imitation of the Oriental products—was set up in Brunswick, England, in 1765. Canework was known and used in late Stuart times, and during the William and Mary period (1688–1702) until the Dutch influence overwhelmed it, that is, throughout the seventeenth century. Under Sheraton, canework returned to vogue, frequently being used in company with satinwood and japanned surfaces. A number of polishing methods were used. A list of prices published in 1788 shows that the cost of polishing the outside of an article with hard wax was twice that of oil polishing; while polishing with turpentine and wax cost half again as much as the oil polishing. Decorative processes were naturally dependent on the woods then obtainable for furniture making. Discovery and exploration of the New World during the fifteenth and sixteenth centuries opened new fields to trade and commerce, and brought many new and valuable woods to England. From 1500 to 1660 oak was the predominant wood, while deal and chestnut were rare and valuable at that time. Walnut was not grown in England until the beginning of the sixteenth century, and was then much esteemed because of its rarity. Mahogany, first noticed for its hardness and durability by a carpenter on Sir Walter Raleigh's ship in 1595, was brought to England and used extensively during the eighteenth century. Much of it came from the West Indies, Jamaica alone exporting 521,300 ft. in 1753. During the eighteenth century many other light and rare woods were used in smaller quantities, among which may be mentioned satinwood, rosewood, amboyna wood, tulipwood, holly, thuja, kingwood, and ebony.

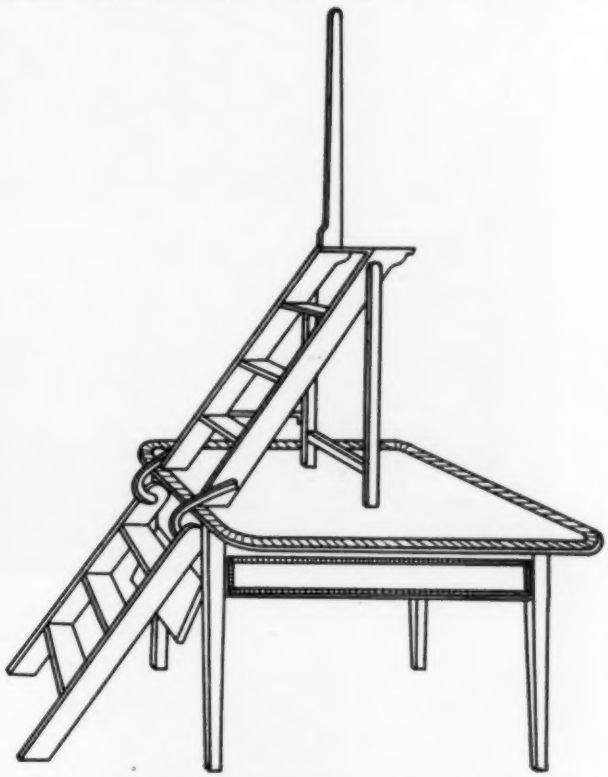


Fig. 5 Pembroke Table and Shelf Ladder, Reproduced From Sheraton's "The Cabinet Maker and Upholsterer's Drawing Book"
(Illustrates ingenious double-purpose design for which Sheraton was noted.)



FIG. 6 LOUIS XIV SOFA, SHOWING GORGEOUS ORNAMENTATION WITH RECTILINEAR CONSTRUCTION
(By courtesy of Metropolitan Museum of Art, New York.)



FIG. 7 LOUIS XV CHAIR
(By courtesy of Furniture Publishing Corporation, Jamestown, N. Y., and Metropolitan Museum of Art, New York.)



FIG. 8 LOUIS XVI CHAIR
(By courtesy of Furniture Publishing Corporation, Jamestown, N. Y., and Metropolitan Museum of Art, New York.)

EARLY HAND TOOLS

Tools employed in furniture making were hand tools. Under Chippendale the beautiful decoration of chair backs and legs was done with the carver's chisel. During the Heppelwhite period, grooving and reeding planes came into use. The legs of chairs, if not left quite plain and square, or simply turned, were ornamented by the use of these planes. Sheraton, in his drawing book, mentions the center bit, the sash saw, and the plane. He was an experienced craftsman, and here and there in his book inserts bits of helpful information about tools to be improvised. Thus he gives instructions, in making a door, ". . . . .for working the astragals (molding or beading) on the edge; which may easily be done, by forming a neat astragal in a piece of soft steel, and fixing it in a notched piece of wood and then work it as a gauge..." Typical hand tools available during that period are illustrated in Figs. 9–13, reproduced by courtesy of the Victoria and Albert Museum of London. Tools in this collection, while dated as far back as 1694, are not the earliest examples known, but are representative of those in general use during the eighteenth century.



FIG. 9 JOINTER'S PLANE, 2 FT., 7 IN. LONG; 3 IN. WIDE, BEECHWOOD, WITH CARVED HANDLES; ENGLISH, DATED 1771



FIG. 10 MOLDING PLANE OF WOOD WITH IRON BLOCK STAMPED ON ONE END, "MICHAEL SAXBY AND F. C. 1756;" LENGTH, 1 FT.; HEIGHT, 6 1/4 IN.

THE NEW ERA

All this time, until the end of the eighteenth century, the action of the drama had been rising to a climax which came with the industrial revolution, when inventions of modern machinery were made in rapid succession.

The tool, removed from the hand of the craftsman and guided instead by some mechanism having a prearranged motion, ceased to be a tool and became a machine. The modern machine is threefold; it consists of the motor mechanism, the transmitting mechanism, and the tool or working element. Such machinery makes possible the use of greater motive force, and greater exactitude in its application.

These developments would seem to offer great advantages, and although one would not expect an ignorant people fully to appreciate them it is rather surprising to known that in 1663, when a Dutchman erected the first sawmill near London, it was attacked by a mob and had to be abandoned because of public disapproval. Even as late as 1768, another sawmill started by James Stansfield was attacked and caused to be abandoned; though in other parts of England mills were started and run successfully by Stansfield with the aid of the government. These were all wind-power mills with jigsaws, until in the year 1777 one Samuel Miller patented a sawmill using a circular blade.

Up to that time inventive progress in woodworking machinery was comparatively slow, but at the end of the eighteenth century there arose a remarkable man, Sir Samuel Bentham, who within a few years invented and patented almost every known variety of woodworking machine.

His father was wealthy and sent him to Westminster School in London, where he completed his studies in 1770. Thereafter he was apprenticed for seven years to the master shipwright of Woolwich dockyard. His apprenticeship served, he spent eighteen months visiting other dockyards, and in 1779 was sent by his government to tour the northern part of Europe, examining the shipbuilding and other arts. In Russia he stayed for some time as a naval engineer, holding, in 1785, the rank of colonel



FIG. 11 (*Top*) MOLDING PLANE, BEECHWOOD CARVED WITH SCROLLS; ENGLISH, DATED 1734; LENGTH, 7 1/2 IN.; WIDTH, 2 3/4 IN. (*Middle*) SKEW-MOUTH FILLISTER PLANE, BEECHWOOD CARVED WITH SCROLLS; ENGLISH, DATED 1744; LENGTH, 7 3/4 IN.; WIDTH, 2 5/8 IN. (*Bottom*) SKEW-MOUTH REBATE PLANE, BEECHWOOD, CARVED WITH SCROLLS, ENGLISH, DATED 1766; LENGTH, 7 7/8 IN.; WIDTH, 2 3/8 IN.

(Reproduced by permission of Albert and Victoria Museum, London.)

in the Russian army. Here he devised a plan for the central inspection of his Russian shipwrights, a method afterward suggested as a means of supervising convicts. Shortly after 1779, while still on his tour, Bentham invented the first planing machine for wood that really could be called an organized operating

machine. The one patented in England in 1776, by Hatton (see Fig. 14), is almost too crude to be considered.

In 1791 Bentham returned to England, where later he became brigadier-general and inspector-general of the naval works of England. Here he found his brother, Jeremy Bentham (the famous writer on political economy) in charge of a number of industrial prisons, containing ignorant convicts who must nevertheless be put to profitable work. Apparently they were incapable of doing handwork in wood, but perhaps they might be able to run a simple machine; thus reasoned Sir Samuel. He therefore devised a large number of woodworking machines for use in these prisons. The residence of Jeremy, at Queen's Square Place, Westminster (now a part of London), was in 1791 made into the first manufactory of woodcutting machines. In the Bentham factory were made machines for planing, molding, rebating, grooving, mortising, sawing—in coarse and fine woods, in curved, winding, and transverse directions—and shaping wood in all sorts of complicated forms. They even made a machine which could make a highly finished window sash, and another which could make an ornamental carriage wheel, both items finished except for assembling.



FIG. 12 EARLY ENGLISH HAND TOOLS

(Left: Mortise chisel, steel with boxwood handle cut with bands of ornament, dated 1761, length 10 in. Middle: Gouge, steel with boxwood handle, dated 1761, length 8 3/4 in. Right: Screwdriver, steel with boxwood handle, dated 1757, length 9 1/4 in.)



FIG. 13 EARLY ENGLISH HAND TOOLS

(Left: Hammer head and shaft, signed Leander Green, English, dated 1694. Right: Handbrace of turned and carved boxwood, English (?), dated 1642, length 9 3/4 in., diameter of head 1 5/8 in.)

(Reproduced by permission of Albert and Victoria Museum, London, England.)

THE BENTHAM PLANER

Sir Samuel's inventive genius was inexhaustible. In 1791 he issued his first recorded patent, for a planing machine, which was in principle an enormous handplane with elaborate mechanisms for passing it forward and back along the stock. Bentham described the essence of the invention as a "method of planing divesting the operation of skill previously necessary, and a reduction of brute force employed." No drawings are included with Bentham's inventions for his stated reason that "they tend to confine the attention to a particular mode, whereas words cover the construction in a general way." It is interesting to note that the British Patent Office of that day sanctioned the omission of drawings.

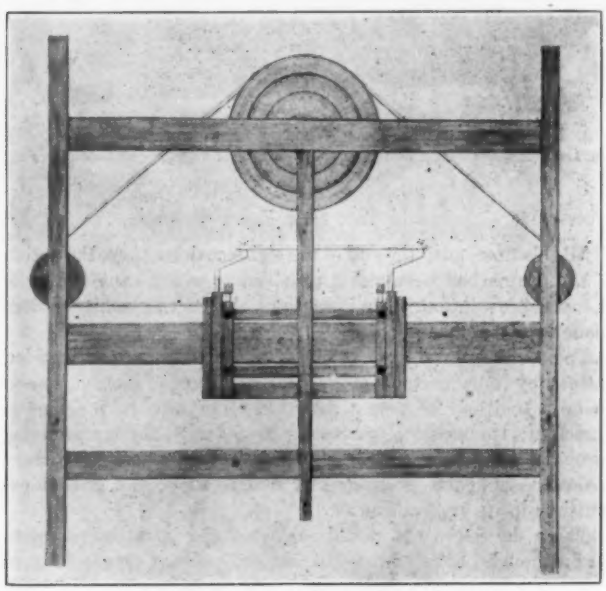


FIG. 14 HATTON'S PLANER

(The first step away from the hand plane. Drawing and description copied from original English Patent No. 1125, issued in 1776. Referring to letters on diagram of planer: *A*, the frame with pulleys and wheels; *B*, the bench on which wood to be planed or fluted is laid; *C*, the bar which keeps the sliding frame in a line; *D*, the sliding frame with closing screws and stock screws; *E*, the stock in which are fixed the several tools for planing and fluting; *F*, the pendulum or handle for moving the sliding stock and tools. By moving *F* backward and forward to the outlines *A*, the work is performed by the tools lodged in *E*, the wood to be planed or fluted lieing on *B*.)

In the Bentham planer the bit or knife is as wide as the stock to be planed; the board is laid on a bench longer than itself; "cheeks" extend down over the sides of the knives; and the ends of the plane are rounded to rise up on the board. As the cut is started, a movable weight is pressed down on the front end of the plane, being shifted to the rear as the stroke is finished, while means are provided to raise the knife on the return stroke. A compound bench to support warped boards at the middle and two sides, and multiple bits to take successive cuts with one pass, are proposed. The suggested motive power is "wind, water, steam, or animal strength."

This planer, merely a development of Hatton's idea, was hardly prophetic of Bentham's following inventions, comprising British Patent No. 1951, issued in the year 1793. Few men have had the honor to cover their chosen industry so thoroughly with patents as did Bentham with this single application. In one all-inclusive document he originated, with broad claims, practically every woodworking machine and process that is in use today. The eleven sections of the patent, each describing a machine or process in general terms and without drawings, are worthy of detailed mention.

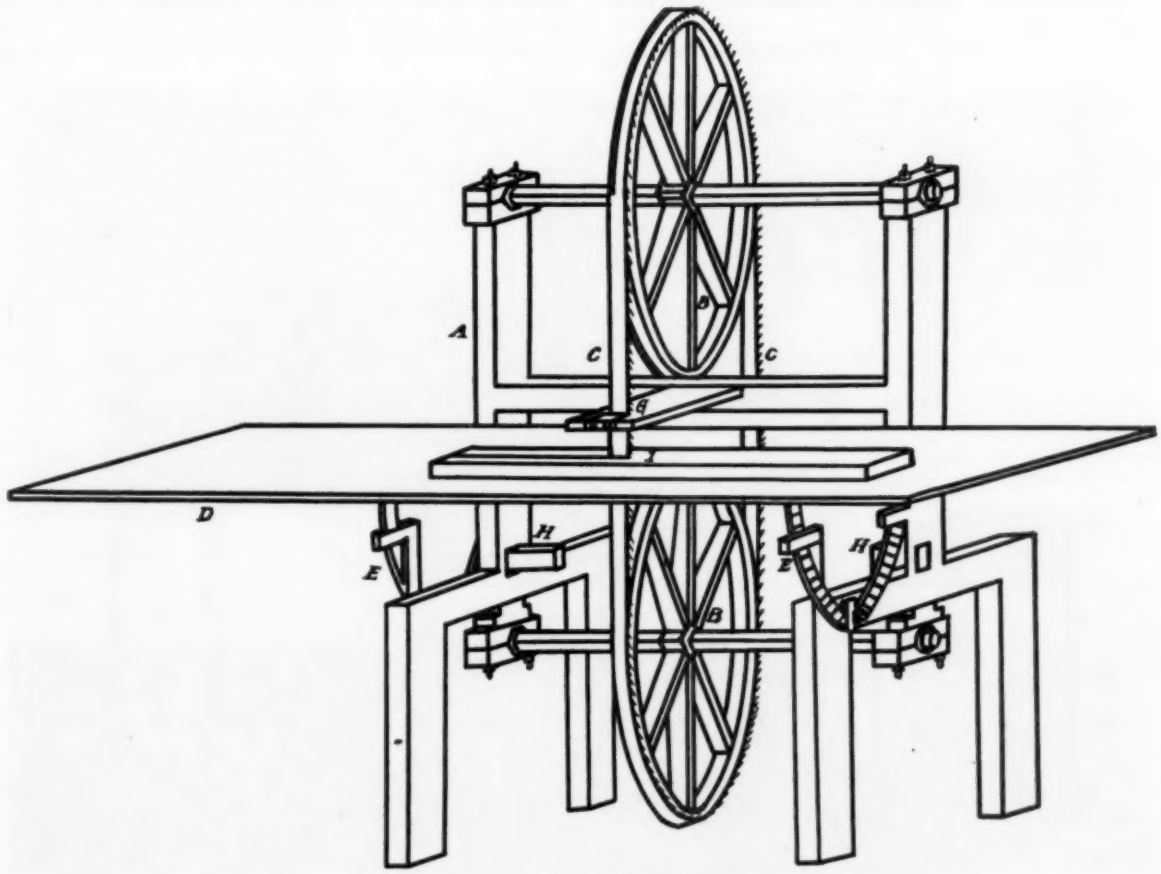


FIG. 15 NEWBERRY'S BANDSAW

(The first bandsaw, patented in year 1808. Drawing and description copied from original English Patent No. 3105. Referring to letters on drawing: *A*, cast-iron frame to carry on wheels; *BB*, wheels with iron plate screwed behind to prevent saw running off backward; *CC*, blade of saw; *D*, bench for piece being cut; *EE*, two semicircles of iron, fixed to *D* whose centers are parallel to part of saw blade which is even with top of bench, one marked with divisions of circle by which, turning on slides, bench may be placed at any angle; *G*, guide to keep saw line; *HH*, wedges to force down lower wheel to give saw tension; *I*, piece to be cut.)

THE COMPREHENSIVE BENTHAM PATENT

SECTION I. "Formations of Laminated Wood from Shavings." The shavings referred to are veneers, cut by the Bentham planer of 1791. This claim describes the first plywood panels, with additional specifications for winding veneers spirally on mandrels to make hollow tubes.

SECTION II. "Sawing by Reciprocate Motion." This section describes a vertically reciprocating saw, with means to handle stock for curves as well as straight cuts—the first jigsaw.

SECTION III. "Working by a Reciprocate Lathe." In this device the work, instead of the "jigsaw blade," is put in the reciprocating frame, and any shape produced by holding a tool against the work. As Bentham frequently refers to the use of this machine for working metals as well as wood, this claim easily covers the present-day metal-working planer.

SECTION IV. "Giving Curvature by Bending." Bentham here states that bending wood by wetting has been practiced from time immemorial, but claims originality for his specified process of building up a thick section in thin plies, making it easier to bend.

SECTION V. "Working by Rotative Motion of Tool." This is a notable section covering every circular-saw table, molder, or shaper in use today. Bentham describes saw tables with either blade or table tilting; describes the present-day cross-cut and rip fences; specifies driving the saw spindle by either belt or gear; gives methods of cutting wedges with a circular saw; describes the use of wide cutters instead of a saw blade; provides for adjustment of a spindle vertically with the table for shaper work; describes the production of moldings; describes both solid and inserted-knife cylinders; and suggests the use of wide rotating cutters in place of his 1791 planer.

SECTION VI. "Boring." This section includes details of core or plug boring, double-end drilling machines for boring long logs, and multiple-spindle drills.

SECTION VII. "Mortising." Machines described in this section mortise with a rotating and traversing bit with a flat end. The blind mortises are squared at the ends with a stamping chisel; and through, or "pervious," mortises are squared either with a square rasp or a "rasping punch," which is in reality a modern broach, the section progressing from round to square.

SECTION VIII. "Turning in a Lathe." Herein are described

methods of reproducing irregular shapes by means of a form for grinding the tool in a lathe.

SECTION IX. "Adjustment and Steadiment." This section gives practical methods of adjusting and holding work to saws and cutters of all machines.

SECTION X. "Advancement." This section broadly covers all methods of moving stock in contact with cutters, or vice versa. It describes the use of gearing connected with a rotative cutter for advancing the stock, long feed screws, gear and rack feeds, and the use of weights or springs.

SECTION XI. "Clearance." Here are methods of removing chips or abraded matter from saw teeth or cutters, such as using air to blow away chips, or having brushes to pass through the teeth of the saw.

Finally Bentham states that the above-described methods are "the fruit of my own invention matured more or less by my own practice." He suggests in addition to the well-known motive power, the installation of his machines in a carriage, if not too bulky, "deriving the power from the wheels on which the carriage runs, in this way, besides the advantage of portability, the power of horses or other beasts of draught may be applied at an expense less than that of erecting a horse mill."



FIG. 16 MODERN GRAND PIANO IN STYLE OF LOUIS XVI; WALNUT CARVINGS FROM SOLID, PRODUCED WITH MODERN MACHINERY AT A COST IMPOSSIBLE TO ATTAIN WITH HAND METHODS
(Courtesy of Chickering and Sons, Boston.)

THE NEWBERRY BANDSAW

Thus in one stroke did Bentham blanket the woodworking industries, leaving unmentioned only the scroll bandsaw, which was invented in 1808 by another Englishman, William Newberry. (See Fig. 15.) It is worthy of note, however, that the bandsaw did not come into general use for nearly fifty years, when in 1855 M. Perin, of Paris, France, exhibited at the French International Exhibition a bandsaw with greatly improved blades, capable of delivering a reasonable amount of service before breakage.

By this time none of the great cabinetmakers were living. They made their beautiful furniture during the eighteenth century, before power woodworking machinery was known or used. Even when Bentham made his machines it is probable that they were not much used by cabinetmakers, for they were rough, heavy machines, more suitable for cutting ship timbers than fine pieces of furniture. It must be remembered that Sir Samuel Bentham was a naval engineer, not a cabinetmaker. There is no record that any of the great cabinetmakers ever invented or made power woodworking machinery, though many of them as Chippendale and Heppelwhite, were practical craftsmen.

During the seventeenth century the use of hand woodworking tools had reached the zenith of development. A long background of experience enabled men to wield their hand tools with the skill of the artist, and to produce works of art in wood. The care expended on each piece was necessarily great, because it was done all by hand. Each article was executed as an individual work, not as one of a thousand similar pieces. If the cabinetmakers had employed the crude machines at their disposal toward the end of the century they probably would have produced crude, unbeautiful furniture, for men were not yet masters of the new machines.

As it was, the quiet atmosphere of preindustrialized cabinetmaking gave time and opportunity for the painstaking labor of a master designer and craftsman who took personal pride in his work; whereas now much of the furniture is made by hired laborers who are not intelligently interested in the artistry of their product. While in the old days beautiful furniture was hand-

made, rare, and available only for the few, today mass production has changed matters entirely. Beautiful furniture now is machine made—with greater precision, uniformity, and strength than the best of the old cabinetmakers could attain; it is abundant, and available to the great majority of people. Of the two eras, the old and the new, there are few of this generation who will hesitate, even though they may regret the passing of the old cabinetmakers, to choose modern industrial methods as best.

CHRONOLOGY

1565. First known veneer mill set up in Augsburg, Germany, by Renner.
1595. Mahogany first brought to England by Sir Walter Raleigh.
1663. First sawmill erected near London.
1765. Manufactory of varnishes set up in Brunswick, England.
1768. Sawmill erected in England by Stansfield.
1769. Steam engine invented by James Watt.
1603–1688. Jacobean Period.
1688–1702. William and Mary Period.
1643–1715. Louis XIV Period.
1702–1750. Queen Anne Period.
1715–1774. Louis XV Period.
1740–1780. Chippendale Style.
1762–1795. Adam Style.
1765–1795. Heppelwhite Style.
1774–1793. Louis XVI Period.
1780–1808. Sheraton Style.
1776. First planer patented by Hatton.
1777. Sawmill with circular blade patented by Miller.
1791. First manufactory of woodworking machinery set up in London by Bentham. Improved planer patented.
1793. Bentham's patent covering many woodworking machines.
1808. Bandsaw patented by Newberry.

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Discussion

DR. HENRY C. MERCER.[3] As to the dead leveling by hand tools before machinery, among the chief agents of this were:

(*A*) The long jointer plane. We find on broadaxe-hewn ceiling beams or on dazed-surface furniture, also on the war clubs, oars, etc. of primitive peoples, dugout canoes, Anglo American bowls, spoons, paddles, etc. made with the draw knife (straight bladed or scooped), what might be called the "hills and valleys" of a waved surface, showing a gentle play of light and shadow, as observed by the sculptor on human flesh. Subsequent polishing or smoothing does not obliterate these wavings, but the long jointer plane, reducing the surface to a dead level, effaces them. Compare most interior walls of newly built houses today, spoiled by dead leveling with the plasterer's float, 5 to 6 ft. long, which no amount of subsequent "brooming" will cure.

(*B*) The broad-bladed hand saw, or pit saw. This will also super-level a wood surface, whereas the old thin-bladed saw, or still thinner-bladed bow saw, if not worked too accurately would not do this.

(*C*) The turning lathe. This would least of all take the life out of a piece of old woodwork, because the turner might neglect his calipers, and so vary the size and interspacing of his swells, or his lathe may be inaccurate and wabble. This latter alleged defect, in the writer's opinion, gives vitality to the Arab turnings of window lattices, etc. The writers of the seventeenth and eighteenth century, oblivious to this fact, strove for accuracy, and despised a wabbling lathe. A comparison between the retouched and not retouched earthenware of the past easily proves that the porcelain of Sevres and the wares of Japan, China, and ancient Greece have been blighted by what is known, but very rarely described, as dry-lathe turning.

Polishing or smoothing, as frequently practiced by primitive peoples and medieval woodworkers, still leaves the "hills and valleys" and has nothing to do with dead leveling.

As to the accuracy of the compass, the square, the gage, and the calipers, a very great charm at once appears when these tools are not used carefully and when, as often occurs in China, corners, distances, centers, and circles are guessed at by eye. Compare the colored plates made by accurate metal workers for Shaw's "Book of Tiles," where in the tile patterns (supposed to be represented, but falsified) the mechanics made the right side of a pattern duplicate the left. Then look at the original tiles in the British Museum which show that the monks made their designs by eye.

The art of the craftsman should be adapted to the raw material worked upon. The law of all wood is a more or less straight grain. Heppelwhite, Sheraton, Chippendale, etc. violated this law by dangerously cutting and deeply notching across the grain. Such carvers as Grinling Gibbons went beyond all reason by producing projections which look as if they would blow away if breathed upon. The medieval craftsmen carved close, and their work at once belittles the wood silhouettes of Chippendale and his school.

The foregoing defects appearing in the hand-made woodwork of the eighteenth century were all exaggerated by the machines of the industrial revolution now in use. One chair by Heppelwhite, too accurate individually, might vary somewhat in a second chair of the same type, whereas now a thousand chairs would be exactly alike. Nothing here said is meant to belittle machinery in its proper place. But the place of a machine is not in the field of art. If a piece of furniture is a work of art, we have not yet realized that no work of art can be made by a machine.

THOMAS D. PERRY.[4] In their researches did the authors come upon a number of illustrations of woodworking machinery, man-power, horsepower and water-power, published in the Theatrum Machinarium Novum in Nuremburg in 1662? These were evidently ideals of the author rather than actual examples of practice.

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Firesafe Lumber

By RAYMOND W. STORM,[1] NEW YORK, N. Y.

Methods are given of rendering wood non-inflammable by impregnation with various chemicals in aqueous solutions, together with the subsequent drying of the treated lumber and the important characteristics of the products thus produced. The author has sought to emphasize mainly the commercial or practical side of manufacture and use rather than the purely technical or theoretical aspects of "Firesafe" wood.

AS EARLY as the first century A.D., the Romans, under Emperor Augustus, recognized the value of fire-resistant wood and employed a coating of alumina and acetic acid (clay and vinegar) which was plastered on over wooden building members, much as we might today enclose with Kalamein metal or encase our steel structures with concrete. This coating actually provided a fair amount of fire resistance, although of course impractical from the modern viewpoint. Thereafter, up through the Middle Ages, the absence of historical data indicates that "fireproof" wood seems to have been almost entirely neglected, although in 1841 Dr. Pyne, an Englishman, patented a sodium-tungstate treatment.

Attesting the more recent interest in "fireproof" wood, there are to be found in the United States Patent Office hundreds of patents, domestic and foreign, covering principally solutions of salts in myriads of combinations—ammonium chloride, phosphate, and sulphate predominating. A generation ago in New York City there existed a wood-treating plant which actually produced lumber which, from the standpoint of comparative fire resistance at least, was admirable. In the past decade, in fact, several plants have been established in the United States for the "fireproof" treatment of lumber, and apparently most of these plants have been moderately successful.

The impregnated lumber made by these pioneers was and is acceptable to the New York Bureau of Buildings, which first promulgated about 1900 the tests which are still in use, only minor changes having since been made, and which apply on all buildings over 150 feet in height. The Building Inspector in charge selects, preferably at the job, samples from each 2000 ft. of lumber and takes them to the official testing laboratory at Columbia University. If the samples fail in these tests, the builder is not permitted to use the lumber.

Due to excessively high costs, limited production, and especially the deliquescent nature of the chemicals used, the use of "fireproof" wood has been limited and it is not widely known. Some cases are reported where the treated lumber, being extremely hygroscopic, has attracted moisture to such an extent that globules of water (or solution) formed on the surface, causing leaching, and gradually by capillary attraction and evaporation removing some of the chemicals from the wood. In other instances, during periods of great humidity, varnished or painted woodwork has been known to have been damaged by the efflorescence of the salts. This affinity for moisture has, in fact, been the greatest stumbling block in the way of previous large development, and quite naturally it has in some quarters prejudiced people against "fireproof" wood.

When used in dry places, however, this material has generally been satisfactory. In fact, one great good has developed from these early treatments—it has been definitely shown that "fireproof" wood once dry and kept dry could be counted upon to retain its effectivity. Numerous examples of this are to be found. One of definite record is a test (see Appendix No. 3) made at Columbia University on August 1, 1929, of samples of "fireproof" trim



FIG. 1 CORNER OF LABORATORY WHERE FORMULAS ARE TRIED OUT

treated in 1912 and 1913, and removed from the Hotels McAlpin and Biltmore and 80 Maiden Lane in 1929. This and similar tests have proved invaluable as practical demonstrations of the stability of certain fireproofing chemicals in wood over long periods of actual use.

From the foregoing it is apparent that while considerable progress in the field of "fireproof" wood had been made by the pioneers, there remained, nevertheless, many problems in the creation of new formulas and processes and in the establishment of the product on a sound, scientific, and commercial basis.

RECENT DEVELOPMENT

With these definite purposes in mind, and with the further goal of recovering for their industry at large and their individual businesses in particular the prestige lost in some fields to competitive products, a group of lumbermen, including the Edward Hines Lumber Company, of Chicago, early in 1926 organized the International Fireproof Products Corporation, which company has carried on the program of intensive research and development presently to be described. Operating in three specially built

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[1] Treasurer, International Fireproof Products Corporation; Treasurer, Geo. H. Storm & Co.

Presented at the meeting of the Wood Industries Division of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, New York, N. Y., February 27, 1930, under the auspices of the Metropolitan Section.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

laboratories over a period of three years, the scientists of this company—chemists, engineers, and wood technicians, all specialists in their respective lines—first explored the field of "prior art" and then went on into new realms of research, eventually originating and perfecting the various formulas and processes as used today. Credit for these chemical inventions is due to Fernando Somoza Vivas, senior chemist.

Firesafe Trademark and Formulas

"Fireproof" wood is of course a misnomer, even an impossibility, nothing in nature being completely fireproof. Therefore, at the very outset, a more exact title was found necessary, and the word "Firesafe" coined. This name has become a trademark and must always be definitely associated with the numerous developments of the International Fireproof Products Corporation.

The chemicals used, while covered by a long chain of process patents, some of which have only recently been applied for, naturally cannot be divulged. It may be stated, however, that these chemicals are of several different groups—some that break up at low temperatures (200 to 1500 deg. fahr.), some at medium temperatures (1200 to 3000 deg. fahr.), and some at the highest temperatures found in burning buildings (2000 to 6000 deg. fahr.). These chemicals function in different ways: by giving off a non-inflammable, fire-extinguishing gas, by fusing over the surface of the wood in a protective coating, and by obstructing the pores of the wood and excluding the oxygen necessary to combustion.

All chemicals are dissolved in warm water in proportions established by exhaustive tests. To each gallon of solution is added a small amount of Firesafe "dope," a paste made in our laboratories having a strong catalytic and lubricating effect. It is largely this "dope" which makes Firesafe lumber so much more easy to mill than any other "fireproof" wood, although the careful filtration of the solutions also helps materially, as thereby much insoluble matter is removed which would later deposit on the surface of the lumber, causing abrasion. These are novel "Firesafe" features.

As previously remarked, the most important characteristic of a fireproofing formula is its comparative affinity for moisture, it being safe to assume that all chemicals used in fireproofing are in some degree deliquescent. Firesafe formulas are not offenders in this respect, and the treated wood may be relied upon not to exude chemicals in damp weather, it being practically non-hygroscopic. Lumber stored in open sheds by the East River has shown no dampness 99 per cent of the time, and only at the end of long periods of rain has it showed any surface moisture at all, and that very slight and unimportant.

Description of Firesafe Process

Generally known as the "full-cell" process, the routine of treatment is essentially as follows:

The lumber to be treated is locked in an air-tight retort or cylinder from which the air is evacuated, reaching gradually a vacuum corresponding to about 29 inches of mercury. This vacuum removes from the cells of the wood most of the air and some of the moisture, the latter depending upon the amount of initial heat present in the lumber. After a sufficient period of vacuum, varying with different species and thicknesses, the vacuum is broken by the inrush of chemical solution from the storage tanks, where it has been kept at a temperature of from 100 to 150 deg. fahr., depending upon the formula being used. In these storage tanks mechanical agitators are sometimes employed.

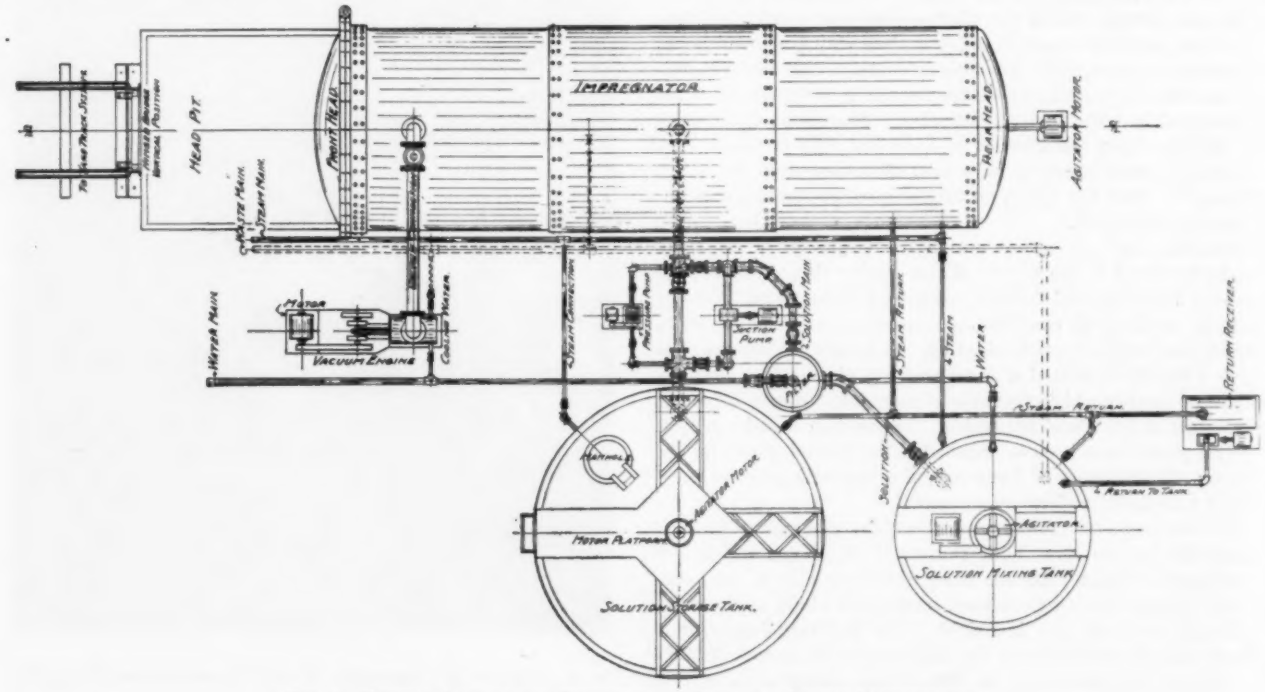


Fig. 2 Typical Layout for Fireproofing Unit for Single Impregnator

A large percentage of the necessary impregnation is obtained by prompt absorption, but when the flow into the cylinder becomes static, pumps are employed to force an additional amount of solution into the wood, pressures of from 100 to 250 lb. per sq. in. being employed. Each gallon is metered as it passes through the supply lines, and a further check is provided by gages on the storage tanks.

In the cylinder even temperatures are maintained by steam coils and recirculation by means of a propeller-type agitator. This cylinder agitator is a unique feature of the Firesafe process and makes for even saturation. Only a carefully controlled

number of gallons per hour per thousand feet board measure is forced into the wood, at a regular rate, until the desired total is reached, when the impregnation is stopped and the superfluous solution returned to the storage tanks by a separate centrifugal pump.

After a brief dripping period, during which the cylinder door is unbolted, the lumber is then removed from the retort.

If necessary, the wet lumber can be immediately placed in a dry kiln, but an oxidation period of one or more days is recommended before the actual mechanical drying starts.

The Dampsafe Treatment

Should the Firesafe lumber be intended for use out of doors or in damp places, a second treatment (before drying) is employed which accomplishes a rapid chemical reaction and renders the chemicals of both treatments insoluble. This reaction is very effective, and the resultant amorphous substance cannot be dissolved in water or even in a 20 per cent solution of hydrochloric acid.

If this reaction could be accomplished evenly throughout the cellular mass of the wood, a perfectly insoluble treatment would result, but due to the active affinity of the two solutions, the union is accomplished more effectively on or near the surface of the lumber. An average penetration of about 1/4 in. is to be expected, which is sufficient for most moisture or exposure conditions, but will not permit immersion in water for long periods without partial leaching of interior chemicals.

This Dampsafe treatment is not water-repellent or waterproof, and is rather to be likened to the condition of a brick which due to its porosity may absorb and exude moisture without deleterious effect. The result is decidedly non-hygroscopic lumber. There is noticeable, however, a slight surface deposit of a white, granular substance, easily brushed off, but which renders this doubly treated lumber hard to plane, although it may otherwise be cut easily.

While the Firesafe and Dampsafe treatments may be handled in one retort, provided careful washing is done between, a separate cylinder for the second treatment is recommended.

"Dampsafe" lumber is a novelty, and greatly enlarges the field of merely Firesafe stock.

It must also be added that Dampsafe lumber is largely non-corrosive, neutral, and non-poisonous. Ordinary wire nails have shown practically no corrosion after months of exposure in Dampsafe lumber.

An interesting phase of Dampsafe lumber is that under air conditions it dries more rapidly. In fact, for ordinary structural purposes, especially in partially impregnated stock (explained elsewhere), nothing more is recommended than air drying for a period of a few weeks.

Freedom from rot and greatly increased resistance to fungus and insect attacks of all kinds will place Dampsafe lumber in a class by itself. Due to the comparative newness of the product, it is impossible at this time to hazard a guess as to how much the Dampsafe treatment increases the useful life of lumber, but it should be considerable.

Finally it must be noted that Dampsafe lumber is not adapted for re-milling—the finished shapes only should be Dampsafed.

The chemicals used in both Firesafe and Dampsafe treatments are harmless and not poisonous; in fact, most of them can be taken internally without injury.

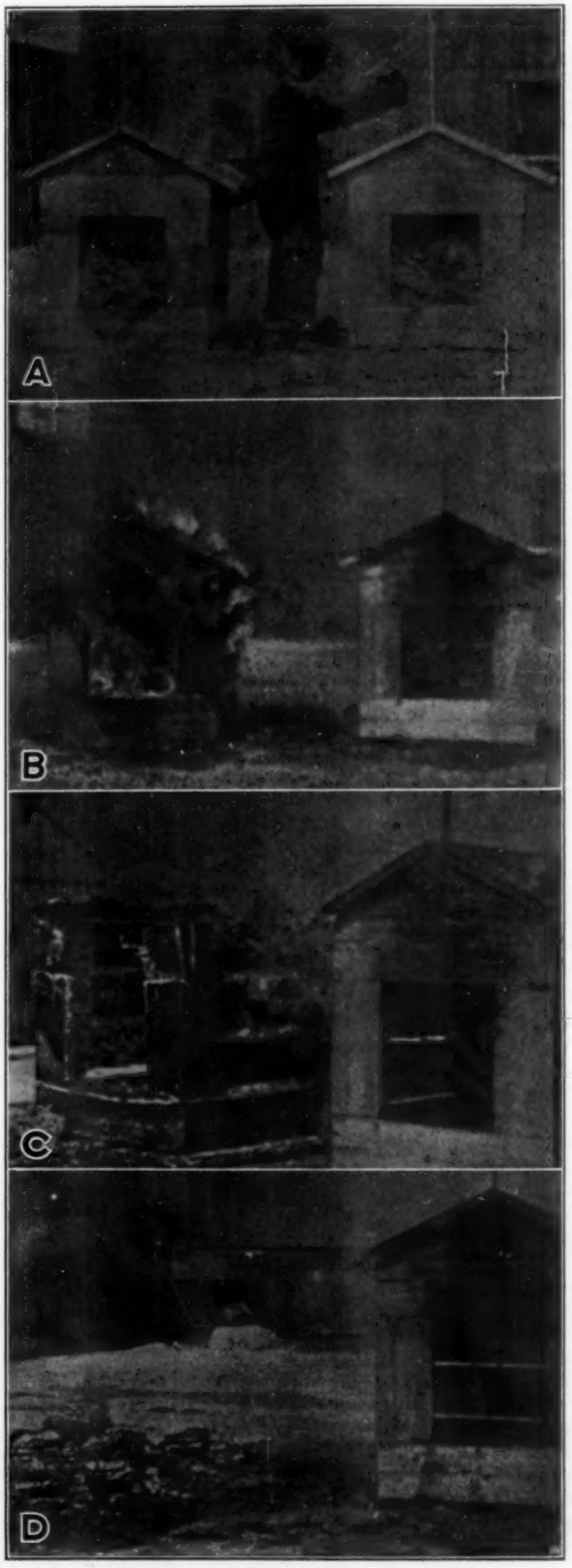


Fig. 3 (*Right*) Test of Comparative Fire Resistance

(*A*, small buildings of ordinary Eastern spruce, filled with excelsior and saturated with kerosene, the one at left not being treated and the one at right being treated by the Firesafe process; *B*, ten minutes after; *C*, twenty minutes after; *D*, thirty minutes after, the untreated wood being entirely consumed, while the Firesafe-treated building is in good condition.)

Partial Impregnation

Great fire resistance is obtained from surface impregnation; almost as much as from the full treatment. The thin coating of Firesafe wood acts like a covering of Kalamein and effectually retards the progress of fire. In a recent public test a flame of 6000 deg. fahr. under heavy pressure was directed at the surface of a piece of partially treated spruce lumber for a period of five minutes with only a shallow charred spot, the diameter of the flame, resulting.

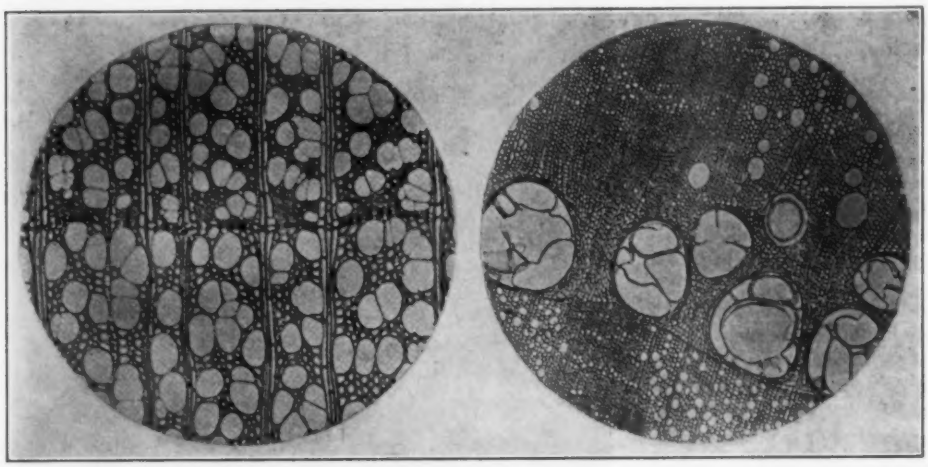


Fig. 4 Variations in Wood Structure; Poplar at Left and White Oak at Right

A severe practical test is shown in Fig. 3. Two small houses (4 by 4 by 5 ft.) were built from $1^1/_4$ by 9 Canadian spruce, all taken from the same pile. The one at the right was partially treated—that is, it was given the Firesafe and Dampsafe treatments, approximately $^1/_4$ in. deep—and then dried to 15 per cent moisture content. No boards were resawed or split but all were crosscut, exposing untreated ends. The one at the left was built of untreated (natural) stock. The houses were set 2 ft. 6 in. apart, filled with dry excelsior, and each one was saturated, inside and out, with five gallons of kerosene and ignited. The pictures tell the rest of the story.

Partially impregnated stock is ideal for many purposes; in fact, for practically all purposes where the lumber is not to be resawed or milled after treatment. The untreated ends present no danger, as fire will not work in against the end grain of the wood to any extent.

A great saving in cost on partially treated lumber is obvious; less chemicals are used, the drying is easier, and the stock is lighter in weight.

The Firesafe treatment leaves the lumber almost natural in color. It is therefore hard to distinguish, especially when mixed with other lumber on jobs. To prevent fraud and to protect the interests of all concerned, Firesafe lumber is in most cases colored a pale blue. This color may be easily covered by paint and is an important feature of this product. Careful tests show that the blue will not wash out of double-treated stock, although it may eventually fade. In the single-treated stock (Firesafe) it is less fast. Uncolored lumber may be had if desired.

Drying of Firesafe lumber in ordinary kilns is easily accomplished. The average drying time for $^4/_4$ fully treated stock is three to four weeks. In a patented type of vacuum kiln, known as the Triplex Dryer, which has been giving considerable satisfaction, this drying period has been reduced to approximately six days, and experiments are now under way which it is expected will reduce this still further.

Air drying on partially treated stock is recommended whenever the lumber can be piled up "single" for a period of a few weeks.

Species Treated

Wood structure is an important factor in impregnation. Some species are easily treated evenly to a depth of several inches; others are practically impenetrable. The pines, especially sugar pine, white pine, and short-leaf yellow pine, are particularly receptive to Firesafe treatment; also poplar, basswood, birch, and soft-textured red oak; while white oak and the fast-growing red oak of the South are practically impenetrable. The explanation of this is readily seen in the accompanying microphotographs (Fig. 4). Notice the regular spacing of the capillaries in the poplar and the absence of conspicuous bands of non-porous summer growth, and contrast these with the radically different structure of the white oak. Of course, in the white oak, there is a characteristic typical of this particular species (*quercus alba*) in the tyloses, or valves, which occur at frequent intervals in the arteries, closing them completely and setting up an invulnerable barrier to Firesafe solutions.

Then there is another group of difficult woods in the hemlocks and firs. In these occur dense, shell-like sections, non-porous and impenetrable, which effectually interrupt the flow of solution and partition off the softer parts of the lumber. In these woods a half-inch penetration is all that can be expected.

Generally speaking, the following commercial woods can be treated, and are arranged in the order of their receptivity:

First Group—Sugar pine, balsa, genuine white pine, pondosa, Idaho pine, California white pine, short- and long-leaf yellow pine, loblolly, North Carolina pine, chestnut, poplar, basswood, birch, maple, beech, ash, elm, soft-textured red oak

Second Group—Eastern spruce, Western red cedar, white cedar, Sitka spruce, mahogany, Southern red oak, balsam, cypress, walnut, redwood

Third Group—Fir, hemlock, pitchy pine, teak, aromatic red cedar

Fourth Group—White oak, rapid-growing Southern red oak, lignum-vitae, ebony, cocobola, hickory. (To date, these have not been successfully treated.)

General Characteristics

A knowledge of the characteristics of Firesafe wood is extremely necessary before a proper understanding of its qualities can be had. Considering first its negative features, although it will effectually resist combustion it cannot be expected to resist charring. Continued exposure to heat which would ordinarily cause wood to burn will eventually produce slow decomposition (charring). Further, as nature never repeats herself, no two pieces of wood are alike, and obviously some pieces are more receptive to the fireproofing chemicals than others. To impregnate a batch of lumber with enough chemicals so that every splinter in the load is fully treated is possible, but would mean heavy oversaturation in some parts. A commercial process is one in which the general mass of the lumber is rendered non-inflammable and an occasional spot or piece of poorly treated stock is tolerated, providing only that such spots or streaks do not occur in sufficient number to

materially impair the general efficiency of the product. All tests must be representative of the average condition of the lumber and must give an exact indication of what may be expected under actual fire conditions.

A positive fact not previously well understood is that while a piece of "fireproof" wood may be ignited by a match (low temperature), the same piece will show excellent results at very high temperatures due to the fact that only at relatively high temperatures do all the chemicals begin to function.

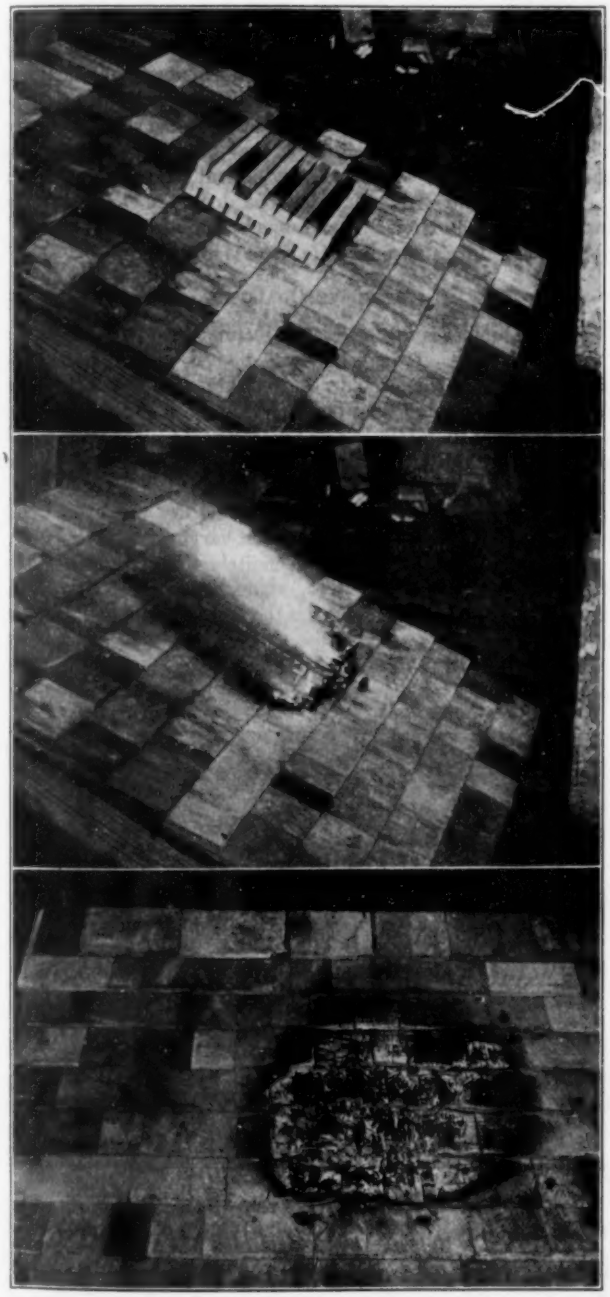


FIG. 5 BURNING BRAND TEST, SHOWING PROGRESS START TO FINISH
(Conditions of test are given in Appendix No. 2.)

EVERY CELL A FIRE EXTINGUISHER

Another fact of paramount importance is that every cell in a "fireproof" board is a diminutive fire extinguisher, for when heated it gives off fire-extinguishing gas. The larger the mass of

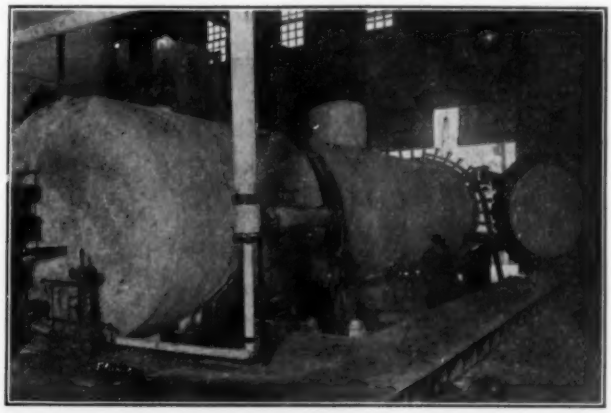


FIG. 6 IMPREGNATOR TANK OF GEO. H. STORM & CO., GENERAL BUILDING LUMBER

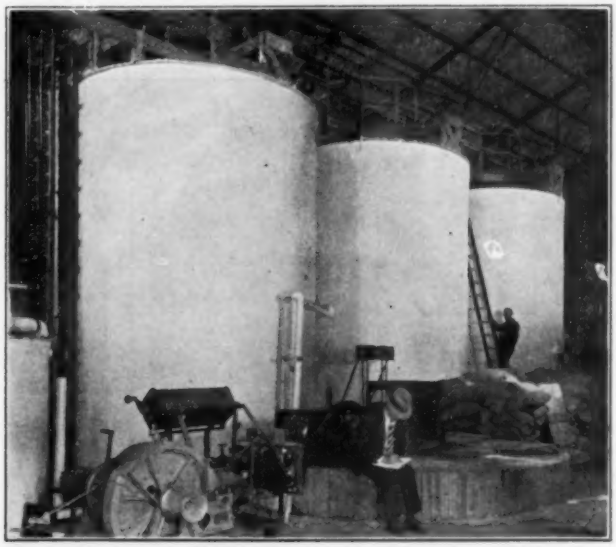


FIG. 7 STORM COMPANY'S STORAGE AND MIXING TANKS

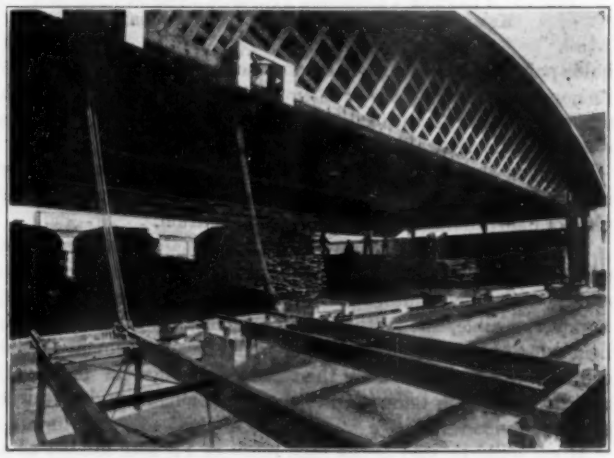


FIG. 8 STORM COMPANY'S LOADING SHED AND TRANSFER TABLE

"fireproof" wood heated, the more noticeable is the result. A "fireproof" wood floor gives off this gas at the base of a fire, the most effective point.

Firesafe wood may be finished like any lumber. It takes and

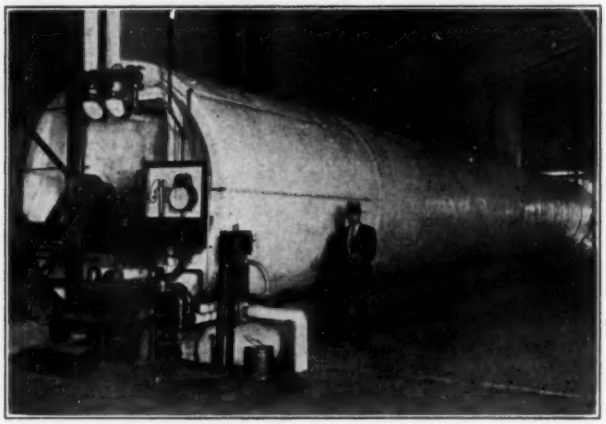


FIG. 9 STORM COMPANY'S TRIPLEX DRIER, TAKING FOUR CARS OF LUMBER

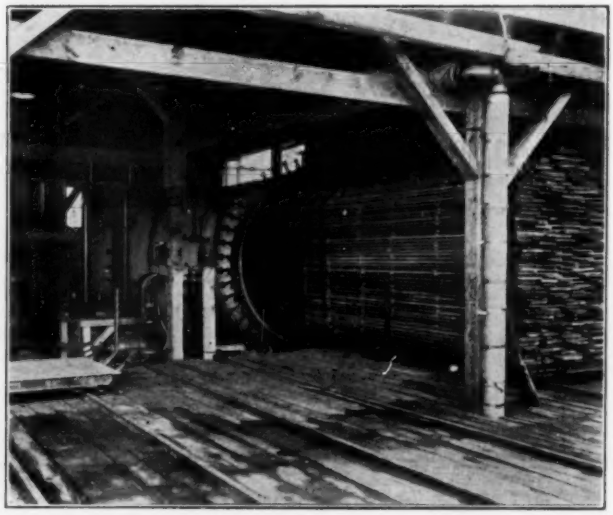


FIG. 10 PLANT OF TENNESSEE FIRESAFE LUMBER COMPANY, KNOXVILLE, MAKING SPECIALTY OF FLOORING

holds paints, varnishes, shellacs, and lacquers very well. Due to its non-hygroscopicity the problem of finishing, a difficulty which was encountered on earlier kinds of "fireproof" lumber, is in this case not difficult at all.

In gluing the same advantage applies. Glue joints made by numerous cabinet makers have been highly satisfactory, and after tests of many months still show no deterioration.

The strength of partially treated stock remains practically the same as before treatment, but a loss of 10 to 20 per cent must be expected on fully impregnated lumber. The treated lumber is, however, flexible, soft-textured, and resilient, any loss in strength being due only to a partial and sporadic disarrangement of the cell structure occasioned by the repeated changes in pressures, rapid variations in temperature, the transitions from dry to wet state, and vice versa.

Much could be said of the high merit of Firesafe lumber as a non-conductor of heat. Of course, wood generally is excellent in this regard, but not at high temperatures where combustion results. The Firesafe treatment makes available this natural excellence, as Firesafe wood even when heated above the flash point transmits the heat very slowly. So much so, in fact, that applying 1700 deg. fahr. to one side of a piece of $^1/_4$ in. thick Firesafe lumber for a period of five minutes raises the temperature of the opposite side very slightly. Thus a Firesafe wood door is vastly superior to a steel door as a fire stop. In actual tests Firesafe wood doors have withstood the direct attack of a severe fire five times as long as a standard Kalamein door and four times as long as a solid steel door. This means vastly greater protection. In addition to this, it must be remembered that a Firesafe wood door is easy to fit, meaning that less smoke will escape through the cracks, while it is very difficult to make Kalamein doors smoketight. Also Firesafe wood doors are comparatively inexpensive, and extremely handsome in appearance.

In electrical resistance Firesafe wood is low.

ABRASIVE QUALITIES

Firesafe lumber is much easier to manufacture than any other "fireproof" wood. It may be easily planed, sawed, and sandpapered. On machine molder knives, however, it means more frequent resharpening than on untreated stock, due principally to the fact that there is 20 per cent more mass to cut. High-speed machines and hard-steel knives which may be resharpened while in operation are the answers to this problem.

The average full treatment increases the dry weight of wood about 20 per cent; the partial treatment varying proportionately.

The question of cost cannot be definitely answered, as the cost varies with production, species, and sizes of lumber treated. In the average suburban residence the cost of making all lumber and shingles Firesafe would be not over 5 per cent of the total cost of the house. To use Firesafe trim, floors, doors, etc., in a "fireproof" city office building would increase the cost of the building

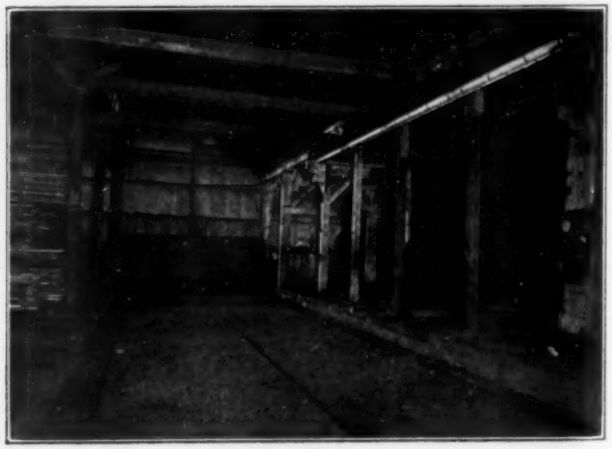


FIG. 11 PLANT OF SLOANE & MOLLER, NEW YORK, MAKING SPECIALTY OF TRIM

less than $1^1/_2$ per cent. To build a mill or factory building with Firesafe wood beams, floors, partitions, and roof would effect a saving over steel and concrete construction in these items of more than 25 per cent—and the building could be erected much more quickly regardless of weather conditions and would be superior in many ways. Firesafe wood partitions are cheaper, better looking, and far more fire-resistant than steel partitions. Firesafe wood-shingle roofs are most handsome, far warmer in winter and cooler in summer, and cost a minor fraction of the price of a good slate or tile roof.

Flooring

Many millions of feet of "fireproof" oak flooring have been used in New York in the last decade or so, and most of these millions have been "bad advertising" for "fireproofed" wood, for the very simple reason that the flooring was treated after manufacture instead of before as it is now being done. The warping, too tight matching, discoloration, and moisture-attracting features of these earlier treatments are a thing of the past. Already a large treating plant, together with a flooring factory, has started operations in the world-renowned, soft-textured oak belt of the Appalachian Mountains, and Firesafe oak flooring of all kinds, treated before manufacture, is now being produced. Builders, architects, and owners can now have all the beauty of oak parquet floors, thoroughly Firesafe, natural in color, perfectly milled, at lower cost than "fireproof" oak floors ever were procured for in the past.

Shingles

The most difficult of all fireproofing jobs is the treatment of wood shingles. Exposed to the elements for many years, "face up," these thin pieces of soft wood must be perfectly Dampsafe if the fireproofing chemicals are to retain their efficiency. Not only are the chemical problems large, but the question of coloring and the mechanics of impregnation and drying are individual problems of this one product.

Suffice it to say that although the many tests now in progress are still incomplete and conclusive data are not yet available, there is sufficient evidence to warrant the opinion that Firesafe

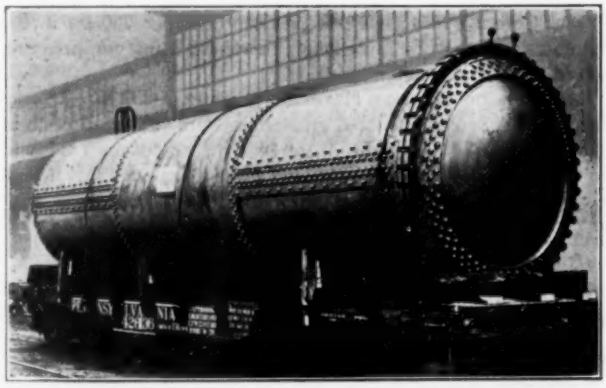


Fig. 12 A Treating Cylinder en Route to Plant of Chesebro-Whitman Company, Long Island City, N. Y., Who Make a Specialty of Scaffolding

shingles are an assured success. After six months of exposure on a roof during which period they were hosed for twenty minutes each day, the shingles show the original fire-resistance. Several laboratories are now running Weatherometer tests, and in a few months definite results will be known.

The Class "A" fire test of the Underwriters' Laboratories is shown in Fig. 3. Time and again Firesafe shingles have withstood the grueling punishment of this test, with no further damage than a charred area equal to the size of the burning brand.

Much success has been attained in the Firesafe treatment of both insulating and panel boards. This is a specialty process however, and must be done during regular manufacture of the boards—a mechanical problem upon which our engineers are now working. The chemical research is practically complete; Firesafe boards retaining full insulating values have been made; and this field, having large potentialities, is about to be opened.

It is not feasible to Firesafe standard panels in board form due to the fact that the interstices of the board are filled, causing a diminution of its insulating efficiency. Further, the problem of drying without warping presents an almost insurmountable obstacle.



Fig. 13 Scaffolding Job of Blue Firesafe Planks on Tubular Steel Uprights

In addition to those uses and applications mentioned, the following should be noted:

Scaffolding, sidewalk bridges, grandstands, stage scenery, motion-picture-studio equipment, airplanes, launches, ships, barracks, storehouses, residences, apartment houses, factories, garages, elevated stations, subway construction, temporary and permanent work in stores, hotels, expositions, furniture, showcases, vaults, storage bins, lockers, and—a most important use—seashore and mountain hotels and cottages.

Conclusion

The development of the Firesafe process has brought to lumber, that "most likable" building material, what has come to other products at earlier stages in their use.

Though tardy, this development is yet in time. It has been a serious work undertaken by responsible interests on a large scale. It has already reached commercial proportions and is growing rapidly. The laboratories are still being maintained, and, naturally, further and continued improvement is to be expected.

Appendix No. 1

REGULATIONS OF THE BUREAU OF BUILDINGS OF THE BOROUGH OF MANHATTAN FOR THE TESTING OF FIREPROOFED WOOD

Before any fireproofed wood may be used for flooring or interior trim where incombustible materials are required under the provisions of Section 356 of the Building Code, the material must be subjected to the following tests, which are to be conducted under the supervision of the superintendent of buildings or his representative, but at the expense of the owner or contractor or other interested party.

The superintendent of buildings must be notified promptly upon the arrival at the job of a consignment of the material. One test sample for each 2000 feet of material will then be selected by a representative of the bureau, marked for identification, and forwarded to the testing laboratory.

(1) For the *shavings test* a mass of shavings cut fairly thick from the outside and interior of sticks of the treated wood are tested separately. These shavings are placed at a depth of 2 inches in a metal vessel 12 inches square, the bottom of which consists of a wire screen of $^1/_2$-inch mesh. The shavings are packed down moderately to reduce the air spaces. A bunsen yellow flame is then placed beneath the receptacle so that the flame is in contact with the shavings. After 25 seconds the flame is removed. The flame at no time should show higher than 6 inches above the top of the bed of shavings and the shavings should not be consumed in less than five minutes.

(2) For the *timber test* two samples $^3/_4$-inch by $1^1/_2$ inches in cross-section and 12 inches long are laid side by side across the top of a gas crucible furnace with a pyrometer between them. The specimens are subjected to a flame at 1700 deg. fahr. for two minutes, the test pieces are then removed, and the time of duration of flame and glow are observed. The sticks are then cut through the middle at the most-burned section, and the area of the unburned wood is measured with a planimeter. The flame must not persist longer than 15 seconds nor the glow longer than 20 seconds; and in the case of hard woods, the unburned area should not be less than 55 per cent, nor in the case of soft woods less than 45 per cent.

(3) For the *crib test* twenty samples are prepared, each $^1/_2$-inch square and 6 inches long. These are built up on a ring support to form a cribwork five tiers high, four sticks to a tier, making the crib 6 inches by 6 inches and approximately $2^1/_2$ inches high. The crib is set 6 inches above a bunsen burner to which the crib is exposed for a period of one minute at a temperature approximating 1200 deg. fahr. The flame must not persist more than 20 seconds after the bunsen burner is removed, nor the glow last more than 30 seconds. The tendency of the flame to spread from stick to stick is also noted.

If the tests are satisfactory the entire shipment is permitted to be taken into the building and used. If not, the entire shipment is condemned and must be removed from the premises.

In general, acceptance is predicated upon the existence of a complete plant in full working order from which the material is shipped; also that each shipment, or where possible each piece, is trademarked in a conspicuous manner so that there may be no doubt as to its identity.

Appendix No. 2

"CLASS A" SHINGLE TEST OF THE FIRE UNDERWRITERS' LABORATORIES

Roof Panel. Make section of roof 4 ft. square with shingles set 4 inches to the weather. Raise "ridge" side so that panel slopes at an angle of 30 deg.

Brand. Cut 30 strips of kiln-dried spruce, extra-fine quality, dressed four sides, 1 inch square by 12 inches long. Have these dried to bone dryness, and the morning of the test nail together 10 strips to the layer, $^1/_4$ inch apart, making a cube with $^1/_4$-inch air spaces throughout.

Fire. Light the brand over a gas flame, and when burning freely, transfer to center of roof panel.

Fan. By means of an electric fan blowing directly against the burning brand, induce a 12-mile-per-hour draft. Continue until brand is burned out.

Shingles should not support combustion, and blaze should not spread.

Discussion

MR. RANDOLPH.[2] How does this affect the cost?

MR. STORM. At present the lumber is sold from $40 to $80 over the cost of the raw wood. We hope to reduce those prices largely with large production.

MR. COHEN.[3] You use one pressure of about 250 lb. in the cylinders. This wood is variable; therefore, using one pressure, would variable results be obtained?

MR. STORM. We use a maximum pressure of 250 lb. In case the wood is dense, we use a greater pressure. The criterion is the saturation of the wood. If the board when cut open is found to be fireproofed in the center, the pressure is enough; if it is not fireproofed in the center, the pressure is not enough.

[2] Western Electric Co.

[3] Bureau of Buildings.

Appendix No. 3

ENGINEERING BUILDING
UNIVERSITY 3200
EXTENSION 33

Columbia University
Department of Civil Engineering
Testing Laboratories
New York City

COMMITTEE ON TESTING
E. B. LOVELL, Chairman of Department
A. H. BEYER, Director of Testing
J. K. FINCH, Secretary
W. J. KREFELD, Engineer of Tests

Tested by D.M.Burmister
Witnessed by Samuel Cohen, Bureau of Buildings
Borough of Manhattan

TESTS UPON "FIREPROOFED WOOD"
STANDARD CROSS-SECTION OF ALL TIMBER SPECIMENS 1½" x ¾"

Date August 1, 1929
Made for Sloane and Moller, Inc.
316 East 65 Street
New York City

TEST NUMBER	MARK	SPECIES	TIMBER TESTS: DURATION FLAME MIN. SEC.	TIMBER TESTS: DURATION GLOW MIN. SEC.	TIMBER TESTS: PER CENT. UNBURNED AREA	SHAVING TESTS: DURATION FLAME MIN. SEC.	SHAVING TESTS: DURATION GLOW MIN. SEC.	SHAVING TESTS: PER CENT. BURNED	SHAVING TESTS: HEIGHT OF FLAME INCHES	CRIB TESTS: DURATION FLAME MIN. SEC.	CRIB TESTS: DURATION GLOW MIN. SEC.	REMARKS
	6805	Birch	0-10	0-0	60.0	0-0				0-6	0-0	Hotel McAlpin
	6806	Oak	0-8	0-0	62.2	0-0				0-10	0-0	80 Maiden Lane
	6807	Birch	0-12	0-0	60.2	0-0				0-8	0-0	Hotel Biltmore
			(Hotel McAlpin Material Installed in 1913									
	Note By R.W.S.		No 80 Maiden Lane Material Installed in 1912									
			Hotel Biltmore Material Installed in 1913									

TESTING LABORATORIES COLUMBIA UNIVERSITY NEW YORK CITY

NOTE: No responsibility is assumed by Columbia University for the results or conclusions of any tests made in these laboratories. Publication of results or tests in full may be made, but it is understood and agreed that no abstract of any report will be published as coming from these laboratories without the written consent of the Committee on Testing.

We have found that we can penetrate red oak and other commercial woods that we are using continually with 250 lb. pressure. From the consumer's standpoint that item is not particularly important. What he is concerned with is that he is getting a completely Firesafe board, Firesafe in the sense that it is saturated throughout. One may find in some places a splinter or an oil pocket which will give a little flame. We tolerate a percentage of that. It might be possible to make a board so fully saturated that it would not flame in any part, but that is not commercial. We want a load of lumber which will pass the usual tests. I do not mean that in a load of lumber every other piece will blaze, but I do mean that there are occasional pieces to be found in a charge of lumber which will give a little flame, but that is only because there are pockets and streaks and knots.

MR. POWER.[4] Is this lumber on sale anywhere or does it have to be obtained by having a car treated?

MR. STORM. We carry quantities of various kinds in stock. We aim to carry a stock of all kinds of Firesafe lumber for a diversified trade.

QUESTION. The extra cost of fireproofing is $40 to $80 per 1000 ft. Is it higher for the lighter or for the heavier sizes?

MR. STORM. It takes a longer time to penetrate the thicker lumber and also longer to dry it. The $40 price is for partially impregnated lumber. It varies with the quantity treated, the kind treated, the thickness, and the amount of impregnation, these four factors governing the price. Boards delivered from stock will have required more in handling, storage, and so forth. The lowest price would be obtained when a customer had carload lots brought in, treated, and promptly reshipped. All of these factors govern the price much as the price of lumber itself is governed. That is not peculiar to this industry.

MR. BLOOM.[5] If this chemical is soluble in water, how is the agitator on the impregnating cylinder necessary?

MR. STORM. There are certain parts of the chemical that are not completely soluble, the solubility varying with the temperature. As the lumber cools down, there is a lessened saturation. The agitator is underneath the cars at one end of the cylinder, and it circulates the solution up through the cars and back through the lumber. We take frequent hydrometer readings so as to maintain an even solution at all times.

MR. DONALD.[6] Have you had any measurements of the insulation value of the treatment, for instance for cold storage?

MR. STORM. We do not claim that the treatment increases the natural insulating qualities of wood. It makes available those natural qualities which cannot be used in ordinary lumber after it is heated up beyond the flash-point.

MR. O'CONNORS.[7] Have you carried on any tests in damp cellars?

MR. STORM. We have stored this material in open sheds by the river front for months at a time, and it has never shown any superficial accumulation of moisture except on very wet days, and then it is slight and unimportant.

RALPH H. MANN.[8] The paper refers to freedom from rot and greatly increased resistance to fungus and insect attacks of all kinds in Dampsafe lumber. The American Wood Preservers' Association deals with the preservative treatments of lumber. If we can combine a preserved stick with a Firesafe stick, the wood industry will receive material benefit. Have any tests been made on safeguarding the timber from fungus rot on top and decay in the stick?

MR. STORM. As to whether we have made tests to show the preserving qualities of our treatment, of course the preserving of the wood up to the present time has been secondary in our minds. It is important, we realize. The double-treated lumber, that is the Dampsafe lumber, placed in very wet locations, as on the ground under lumber sheds, for a period of over two years, shows no fungus attack and no rot. We have not carried the test out more scientifically than that, but we have great confidence in the treatment to resist fungus attack. As to what chemicals were used in the old-style wood-fireproofing methods, they were a combination of chemical salts. The weight put in was about 2¼ lb. per gal. of solution treated, with 280 gal. per 1000 board feet, measured with a lumberman's scale.

MR. DAVIDSON.[9] I might contribute one answer in connection with experience in the deterioration (or less deterioration) of Firesafe scaffold plank. I do not refer to the long-time decaying, but to the deterioration formerly on scaffolding lumber and other lumber that is used over again on structural operations when it is fireproof. We have discovered that we could not expect the scaffolding plank to be used many times because lime and plaster and cement would be ground into the plank, and the traffic across that plank makes it wear out very quickly. Since we have been using Firesafe plank we have discovered that though the lime, cement, and plaster fall on it as before, when it comes back from the job that material can be brushed off. In other words, it does not penetrate the fibers of the wood, and thus the lumber can be used over a good many times, far more than untreated lumber.

B. HUBER.[10] Would the so-called fireproof or treated lumber for fire-retarding purposes, made also dampsafe according to Mr. Storm's idea, have a logical application for roofing boards, lumber piles, and so forth? I understand the ordinary fire-retarded material would leach out unless some other preservative treatment were given to keep that fire-retarding material in. After a course of time the chemicals would leach out. The old cabinetmaker's bogy was the shrinkage and swelling of wood. Does a treatment of this kind promise any relief or aid in retarding the effect of shrinkage or swelling of wood?

MR. STORM. Firesafe and Dampsafe lumber swells and shrinks less than untreated lumber of a similar kind, I should say 50 per cent less. If it is desirable to have roofing boards Firesafe, we would recommend the treatment. If you want a weatherproofing board, something like Valspar varnish or some paint coating probably would give additional protection to the chemical treatment. We do not offer this as a weatherproof coating. We do not know whether a double-treated or Dampsafe board would outlast a board heavily painted with lead and oil paint, for example.

MR. HUBER. But the lead-and-oil painted board would be very highly inflammable as compared with the other. I am seeking to get the advantages of the fireproof or fire-retarded lumber for a covering board and have it last as long or longer.

MR. STORM. It is our feeling that the Firesafe and Dampsafe board will have very long life if exposed to the weather in the same manner as a shingle would have, but if one wanted to expose it for many years, perhaps the fireproof or Dampsafe board should be painted in addition to the fireproofing, and then one would have something more nearly permanent.

MR. JONES.[11] Buildings of non-combustible construction

[4] Board of Transportation.
[5] State College of Forestry.
[6] Consulting Engineer.
[7] Otis Elevator Co.
[8] Service Bureau, American Wood Preservers' Association.
[9] Chesebro-Whitman Co., Long Island City, N. Y.
[10] Steinway Piano Co.
[11] Manufacturers Mutual Fire Insurance Co., New York, N. Y.

have fai'ed in the case of fireproof contents. Take, for example, a building of brick walls, steel frame, concrete floor of steel, supported by steel columns. In case of a hot fire inside, those beams have warped and failed. The floor above has caved in. That means, then, that the steel, although it will not burn, loses its strength. Is this Firesafe lumber so immune that though it will not burn it will still maintain its strength?

MR. STORM. There is a certain loss in strength due to charring. Do you want a comparison between a building constructed of steel and concrete and one constructed purely of wood?

MR. JONES. Suppose a steel beam will support 100 lb. per sq. ft. of floor surface; take the same floor construction of joist, maybe 12 in. apart, centered with a plank on top of the joist or board; will the flooring supported by the beams of steel stand up as long or longer than the wood?

MR. STORM. If the steel is unprotected by concrete, the wooden beam will stand up far longer than steel under the same load. We are now running tests on that.

MR. CARTWRIGHT. I would like to suggest that perhaps the point Mr. Jones seems to have in mind would be settled even more effectively by boxing in either the timber column or the beam or structural shape with an inch or two of fire-retarding treated material, which would not be counted upon for load-bearing capacity, but would be an insulation protection for the structural shape itself.

MR. STORM. We have that in mind. We feel that Firesafe wood as a protective coating for steel has a very large use. We have not carried our tests through on that yet, but we hope to soon. I think it is generally conceded that even a non-treated wooden post, while it may eventually burn up, will not give out as quickly as an unprotected steel post will under identical heat conditions.

(NOTE: Discussion of this paper jointly with that of T. R. Truax and C. A. Harrison by Frank P. Cartwright, Chief Engineer of the National Lumber Manufacturers Association, and by Ernest F. Hartman, President of Protexol Corporation, will be found in the discussion of the latter paper.)

WDI-52-4b

Measuring Fire Resistance of Wood

By T. R. TRUAX[1] and C. A. HARRISON,[1] MADISON, WIS.

The Forest Products Laboratory has devised the fire-tube test to accurately measure in definite terms the property of wood to resist the spread of flame. As an acceptance test, the fire-tube method promises to be useful in evaluating the factors and conditions which affect the fire resistance of wood, as well as a means of working out the problems of those in the business of treating wood with fire retardants.

WOOD, in common with other vegetable materials, decomposes when subjected to high temperatures and evolves inflammable gases. Wood also contains moisture which turns to vapor upon heating. When wood is heated, the moisture vapor is first driven off. If the temperature is increased and heating is continued, resinous and oily materials are volatilized and eventually the wood substance is broken down. During the decomposition both inflammable and non-inflammable gases are evolved, and a combustible residue, the charcoal, is left behind (4).[2] Continued heating of the charcoal at high temperatures in the presence of air causes combustion and a change into carbon dioxide, a non-combustible gas. This whole process of decomposition is accompanied by an evolution of heat. The temperature at which wood ignites and burns depends upon a number of factors, such as the time of heating, the moisture content of the wood, presence of extractives, size of pieces, amount of air available, and density and porosity of the wood. According to Lullin (7), when the temperature reaches 150 deg. cent. (302 deg. fahr.) inflammable gases (hydrocarbons, carbon monoxide) and carbon dioxide are evolved and the wood scorches until 230 deg. cent. (446 deg. fahr.) is reached. From 230 to 270 deg. cent. (446 to 518 deg. fahr.) "red charcoal" is formed, and at 300 deg. cent. (572 deg. fahr.) black charcoal is formed. Norton (10) reports that certain untreated species of wood ignite at 435 to 510 deg. cent. (815 to 950 deg. fahr.) and flash instantly into flame at 510 to 615 deg. cent. (950 to 1139 deg. fahr.). Prince (11) found that untreated woods (oven and air dry) ignited and burned within 15 to 40 minutes when heated at temperatures of 175 to 220 deg. cent. (347 to 428 deg. fahr.). When heated at temperatures of 350 deg. cent. (662 deg. fahr.) ignition occurred within one to three minutes. Likewise, Lullin found the temperature of glowing (incandescence) of different air-dried woods to be between 318 and 368 deg. cent. (604 and 694 deg. fahr.) and of the same woods, previously dried in a vacuum at 100 deg. cent., between 307 and 339 deg. cent. (585 and 642 deg. fahr.). He also found that the glowing temperature for wood charcoal was within the range of 400 to 500 deg. cent. (752 to 932 deg. fahr.), being appreciably higher than for wood. Lullin does not, however, give the time of exposure before glowing or flaming occurred. Hawley and Wise (4) report in connection with wood-distillation work that wood begins to decompose at about 275 deg. cent. and that up to this temperature the main changes that take place are the drying of the wood and the volatilization of various extraneous materials, water being the main product, although some acetic acid and a trace of methanol are formed.

The work of Norton (10), Prince (11), Banfield and Peck (2), and Lullin (7) shows that treating wood with fire-retardant chemicals increases the ignition temperature somewhat. The order of magnitude of this increase was found to be from 0 to about 200 deg. cent., depending upon the kind of chemical used. However, even with thorough impregnation of the wood with concentrated solutions of the most effective fire retardants the ignition temperature is well below the temperature of flames. Both treated and untreated wood char at temperatures which commonly prevail in fires (6). So far as is known no commercial treatment wholly prevents combustion and no treatment can prevent the charring of the wood.

The fire resistance of wood may be considered from a number of points of view. Chief of these are the extent to which it gives off inflammable gases when heated, its resistance to the spread of flame and to the building up of temperatures, its resistance to flame penetration, and its heat insulation. The effects of the treatment on other properties of wood, such as strength, finishing, gluing, hygroscopicity, and corrosion of metals in contact with it are all-important characteristics in the utilization of the wood, but are not a part of fire resistance. Still other properties may be important for certain special uses.

Various Methods of Test

Various attempts, resulting in many forms of tests, have been made to measure the inflammability or fire resistance of wood. In general these attempts may be classified under tests on samples of wood and tests on built-up assemblies under approximate fire conditions. Tests on built-up assemblies are expensive and are therefore limited in their application. This article deals only with the testing of samples or pieces of wood.

The flame-penetration test by which a gas burner or blow-torch flame is applied to a piece of wood has been used by many as a measure of fire resistance. Since it is quickly and easily made with simple apparatus, it has been more extensively employed than more accurate means of tests. In some forms of this test the time required for a flame to burn through a board or timber or for a loaded timber to fail when subjected to the flame is used as the measure of fire resistance (1). The depth of flame penetration in a board, the area of unburned wood in a timber,[3] and the time required for a loaded timber in contact with a flame to fail are essentially measures of the same property—namely, the resistance of wood to flame penetration. Undoubtedly, heat insulation is a most important factor affecting the rate of flame penetration and where possible may well be made a part of the test.[4] In tests of flame penetration, the density of the wood is a very important factor and may affect the results as much as the fire-retardant treatment.

A number of fire-resistant tests are based on measuring the time of flaming and glowing of wood which has been ignited and

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[1] Senior Wood Technologist and Junior Engineer, respectively, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Reference is made by number in parentheses to the bibliography at the end of the report.

Presented at the meeting of the Wood Industries Division of The American Society of Mechanical Engineers, New York, N. Y., February 27, 1930, under the auspices of the Metropolitan Section.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

[3] The City of New York has for some time used tests to determine whether wood meets building code requirements (9). The timber test, one of three tests applied, is based primarily on the unburned cross-sectional area of pieces of wood exposed to a flame for a given time (13).

[4] In some flame-penetration tests made at the Forest Products Laboratory, a thermocouple, insulated from the air, was placed on the opposite side of the board from the flame and the increase in temperature during test was observed.

then removed from the source of ignition. Such tests as the "crib" (9), "splinter" (3) "shavings" (9), "timber" (13), and "muffle" (10) are wholly or in part based on this principle. This form of test has frequently been supplemented by measuring the time required to ignite wood as was done by Prince, or as in the "flue" and "kindling" tests (10) or by measuring the height of the flame as in the shavings, muffle, and "cob house" (10) tests. Most of these tests show differences in fire resistance between wood untreated and effectively treated with fire retardants, but the time required for ignition and of flaming and glowing after ignition depends upon so many conditions that such tests are of doubtful value as an accurate measure of fire resistance. Furthermore, the tendency to flame and glow after removal from

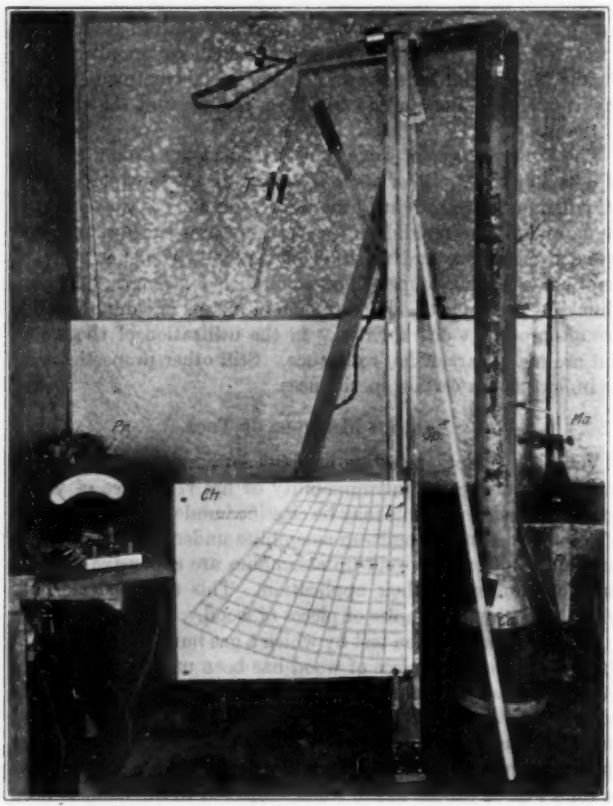


FIG. 1 THE FIRE-TUBE APPARATUS DEVELOPED AT THE FOREST PRODUCTS LABORATORY

a source of heat into ordinary room temperatures does not necessarily indicate the behavior of wood under fire conditions.

Closely related to the time required for ignition is the temperature of ignition. This was used in the "hot plate" test (10) and by Prince (11), Hicks (5), Banfield and Peck (2), and by Lullin (7). The test has been perfected until it is more precise and definite than the time of glowing and flaming, but here again the ignition temperature may or may not measure the essential property of fire resistance. It is possible, for example, for a piece of wood that ignites at a high temperature to continue to burn and give off more heat than a piece which ignites at a lower temperature. It is also true, of course, that wood either untreated or treated with fire retardants ignites at temperatures much below those produced in burning.

McKenna (8) measured the volume and character of gases evolved in heating wood in an electric retort at 680 deg. cent. (1256 deg. fahr.) and attempted to evaluate the fire resistance of wood in this way. Loss in weight during exposure of wood to ignition temperatures was recorded by Prince and Hicks, but neither used it as the principal measure of fire resistance. The spread of flame is also a factor in making certain tests such as the shavings, crib, and flue tests and Prince's inflammability test. No attempt appears to have been made, however, to measure it

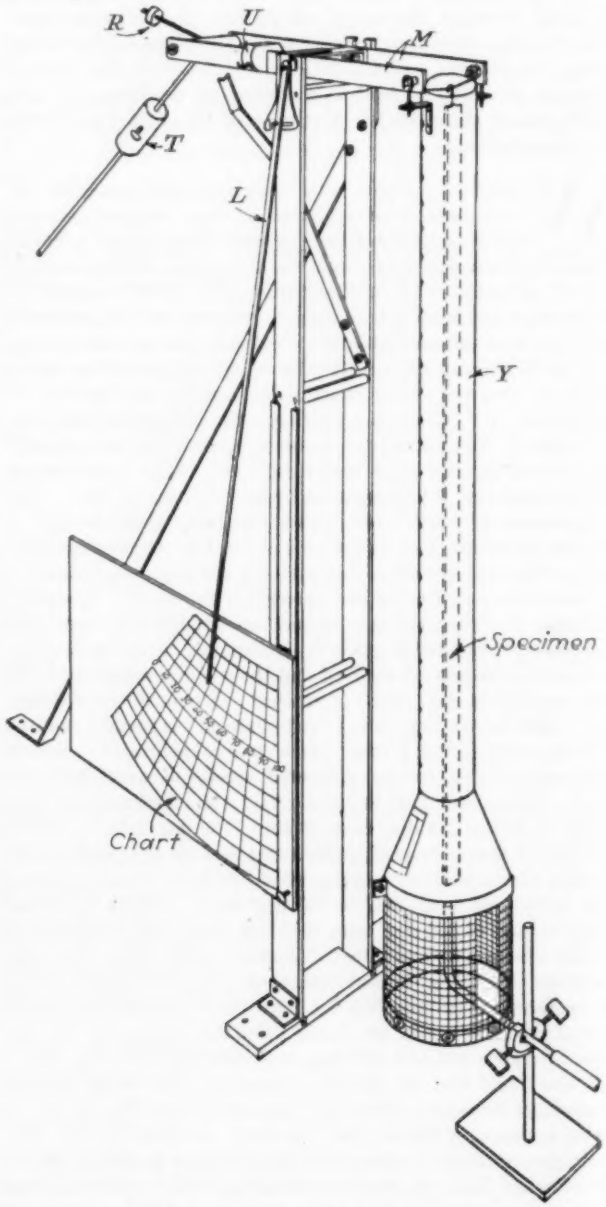


FIG. 2 DRAWING OF THE FIRE-TUBE APPARATUS

accurately or to report it concisely, although it has been recognized as an important factor in fire-resistance (13).

In nearly all the tests referred to comparatively small pieces of wood were used, and in most cases the entire pieces were subjected in test to uniform temperatures. As a result, the entire specimen starts burning at the same time in most tests and affords no direct measure of the tendency of wood to spread flame. It is also felt that greater attention should be given to the property of wood to increase temperatures under incipient fire conditions and thus to contribute to its own destruction. Ignition temperature,

flame penetration, and similar tests do not appear to measure this property adequately.

The Fire-Tube Apparatus

In trying to overcome the limitations of test methods used in the past, M. E. Dunlap, of the Forest Products Laboratory, devised what is now commonly called the "fire tube," shown in Figs. 1 and 2.[5] It is an apparatus which shows directly and progressively during test the loss in weight and the temperatures developed when a specimen of wood is exposed to conditions approximating those existing in fires. Observations are also made of the tendency of the charred wood to glow. It has been used extensively at the Forest Products Laboratory during the past two years and has been compared with certain other forms of test. The results of these investigations show that the fire-tube test has a number of advantages over other forms of test that are commonly used and is very satisfactory for research work. It is sensitive enough to show differences in the inflammability of different species of untreated wood or of the same species of wood at a different moisture content. It shows differences between the effectiveness of different chemicals, differences between various absorptions of the same chemical, and even differences between the outside and the inside of a board completely penetrated with chemical. Furthermore, the test results are expressed

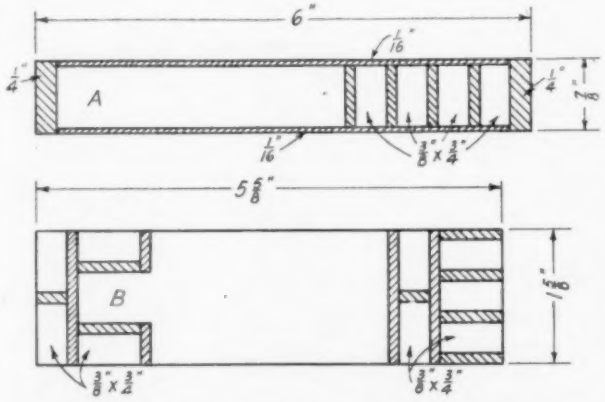


Fig. 3 Methods of Cutting Test Specimens

(*A*, Principal method used in tests described in this paper; surfaced after treatment. *B*, Possible methods of cutting specimens from unsurfaced dimension stock; unsurfaced after treatment.)

numerically and can be duplicated with a reasonable degree of accuracy.

On the other hand, the instrument is not proposed as a complete measure of fire resistance. It gives only part of the information needed in adapting fire-resistant wood to the requirements of the various purposes for which it may be used. Supplementary tests must obviously be employed, for example, to determine how long a load-carrying member will support its load while subjected to fire conditions, how rapidly heat will be transmitted through wood, and perhaps how rapidly flame will penetrate a board.

The Method of Test

In developing and perfecting the apparatus and the details of the testing procedure many tests were made on treated and untreated wood, some of the results of which have been reported (12). The following is a summary of the test procedure adopted as a result of that work:

Specimen. Use a single specimen 40 in. long and 3/8 by 3/4 in. in cross-section, conditioned to constant weight under a uniform relative humidity of 30 per cent and a temperature of 80 deg. fahr. Weigh the specimen immediately before test.

Heat Source. Use a horizontal, low-form bunsen burner, adjusted to give a blue flame 11 in. (±1/2 in.) in height with a tall indistinct inner cone; temperature 1000 deg. cent. (±25 deg.) at the hottest point of the flame and 180 deg. cent. (±5 deg.) at the top of the tube; the top of the burner to be placed 1 in. below the bottom of the specimen.

Duration of Test and Measurement of Results. Leave the ignition flame under the specimen exactly 4 min., and then remove it. Read the percentage loss of weight and the temperature at the top of the tube at 1/2-min. intervals from the beginning of the test until 2 min. after flaming stops. Note also the loss in weight at the exact time the flame goes out and the time at which the temperature reaches the maximum. Also record the tendency of the charcoal to glow after the flaming stops.

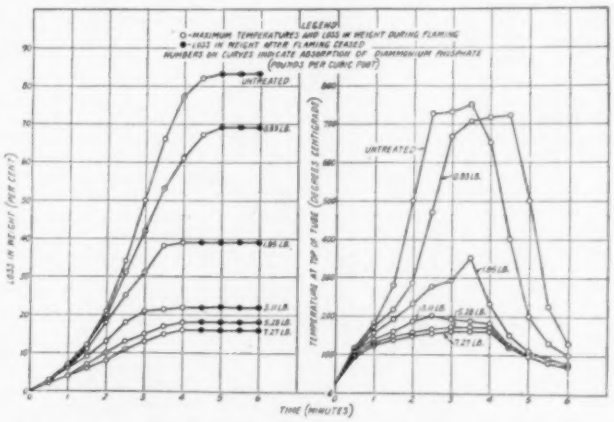


Fig. 4 Typical Loss in Weight and Temperature Curves From the Fire-Tube Test

(Each curve represents a single specimen of Southern yellow pine. Boards surfaced after treatment and drying.)

Preparation of Wood for Test

In preparing wood for test at the Forest Products Laboratory, the treated material is placed on stickers soon after treatment in a room maintained at a relative humidity of 60 per cent and a temperature of 80 deg. fahr. This brings untreated wood to an average moisture content of about 11 per cent. The moisture content of most treated wood will be about the same under these conditions, but some chemicals have considerable attraction for moisture, and wood treated with them may come to equilibrium at a somewhat higher moisture content than untreated wood.

After the boards have come to approximate equilibrium at 60 per cent relative humidity, specimens are cut about 2 in. longer than desired for test and placed in a room maintained at a relative humidity of 30 per cent and a temperature of 80 deg. fahr. This brings untreated wood to a moisture content of between 6 and 7 per cent. On account of the effect of moisture on the results of the test, it is important that the specimens be properly conditioned before testing. After the specimens are constant in weight, and immediately before test, they are trimmed to exactly 40 in., and then weighed and tested.

Boards may be surfaced after treatment or left unsurfaced, depending upon the class of material being tested. In sampling fire-resistant lumber which is to be surfaced before using, such as interior trim, the test boards should be surfaced after treatment and drying, just before the specimens are cut. Likewise, the specimens may be cut through the board from side to side or from one edge or one side depending upon the dimensions and

[5] A complete working drawing of the apparatus may be obtained upon application to the Forest Products Laboratory.

class of material being tested, as shown in Fig. 3, *A* and *B*. For example, lumber for interior trim should be surfaced to about $^{3}/_{4}$ in. in thickness after treatment and drying and the specimens cut from the surfaced boards as in Fig. 3*A*. In the case of dimension stock, such as scaffolding, or floor sleepers, which in practice are not surfaced before using, the specimens may be cut from the surface of the piece, as shown in Fig. 3*B*.

In making a test the empty apparatus is first balanced by means

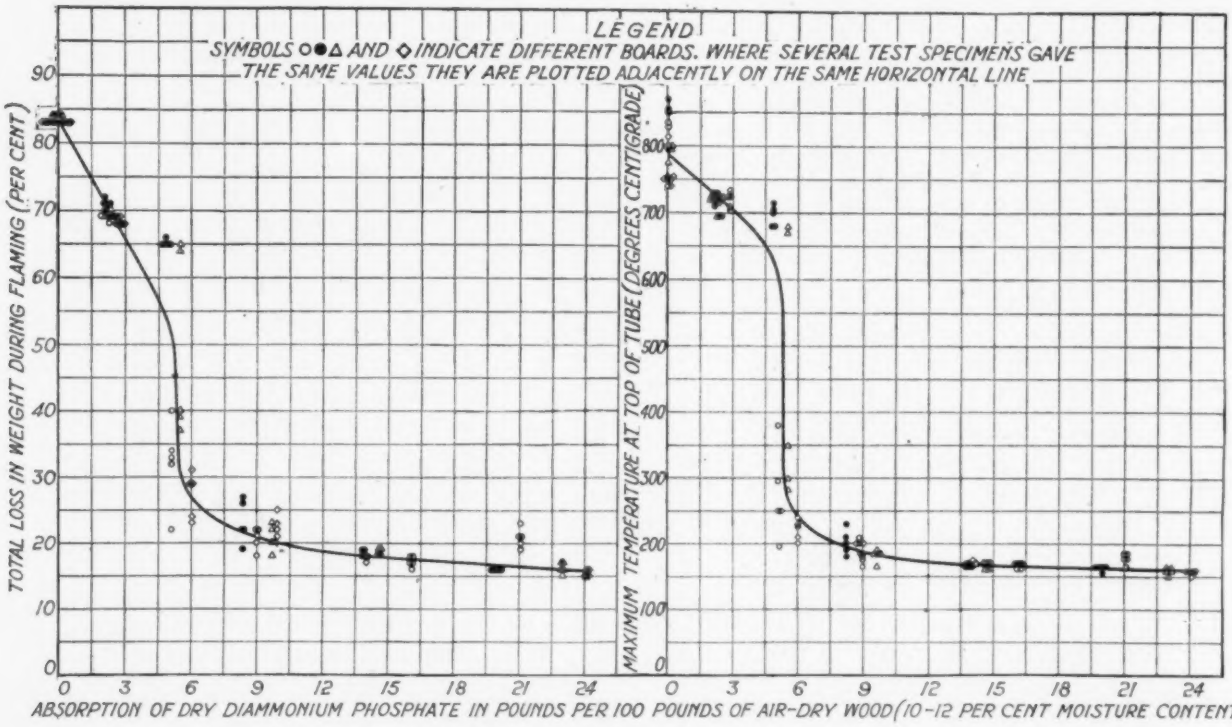


FIG. 5 EFFECT OF DIFFERENT ABSORPTIONS OF DIAMMONIUM PHOSPHATE (EXPRESSED AS PER CENT OF WEIGHT OF WOOD) ON FIRE RESISTANCE OF SOUTHERN YELLOW PINE
(Each point represents a single specimen. Boards surfaced after treatment and drying.)

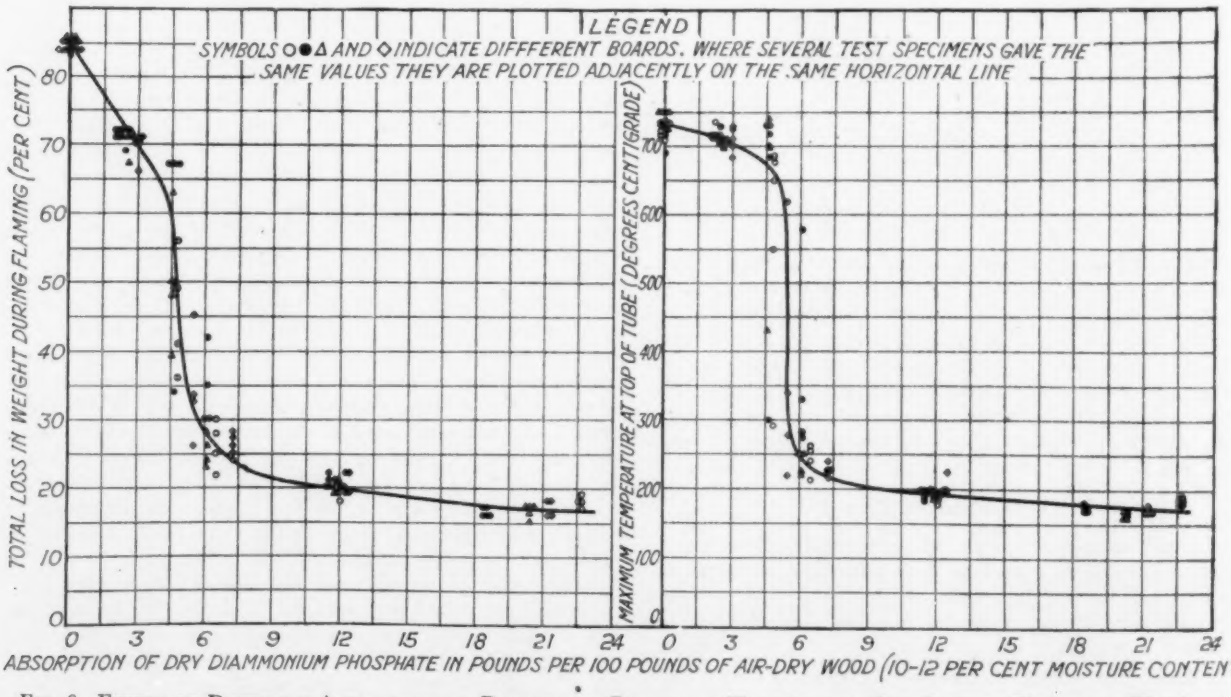


FIG. 6 EFFECT OF DIFFERENT ABSORPTIONS OF DIAMMONIUM PHOSPHATE (EXPRESSED AS PER CENT OF WEIGHT OF WOOD) ON FIRE RESISTANCE OF YELLOW BIRCH
(Each point represents a single specimen. Treated boards surfaced after treatment and drying.)

of counterweights *R*, *T*, and *U*, Fig. 1, so that the pointer *L* will read 100. A specimen *Sp* is then weighed and hung in the fire-tube *Y* by means of a small screw hook in the end of the specimen, which hooks into the top of the tube. The tube, in turn, is suspended from the balance arm *M*. The chart *Ch* is now moved up or down on its slide until the pointer *L* reads 0 when at rest. The gas burner is now inserted through the slot in the cage screen *Ca* at the bottom of the tube, and the flame *Fl* is made to play directly over the bottom end of the test specimen. To compensate for variations in pressure in the gas main, the gas pressure to the burner is kept constant, as shown on a manometer *Ma*, by regulating the valve on the gas line.

An untreated specimen ignites quickly, loses weight rapidly, and builds up relatively high temperatures at the top of the tube. An effectively treated specimen ignites with difficulty, if at all,

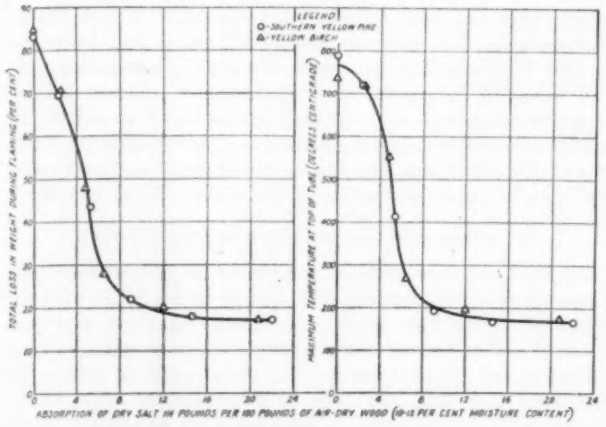


FIG. 7 AVERAGE RESULTS OBTAINED WITH DIFFERENT ABSORPTIONS OF DIAMMONIUM PHOSPHATE IN SOUTHERN YELLOW PINE AND YELLOW BIRCH

(Boards surfaced after treatment and drying. Each plotted point represents from 16 to 20 specimens cut from four boards.)

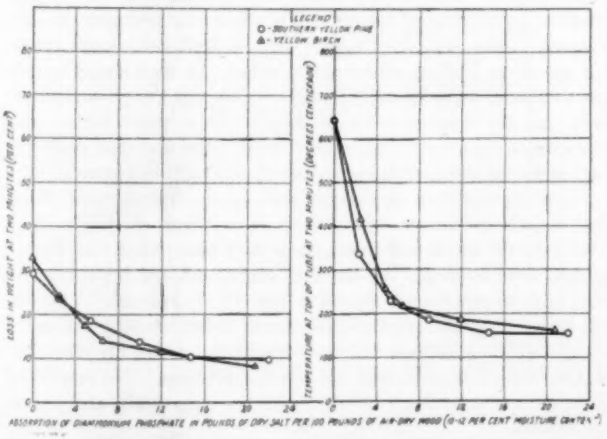


FIG. 8 LOSSES IN WEIGHT AND MAXIMUM TEMPERATURES AT END OF TWO MINUTES. DIAMMONIUM-PHOSPHATE TREATED MATERIAL

(Boards surfaced after treatment and drying. Each plotted point is an average of 16 to 20 specimens from four boards.)

is consumed slowly, and does not build up high temperatures at the top of the tube. When the flame is removed at the end of 4 min., an effectively treated specimen will cease burning very quickly, but an untreated specimen will continue to burn unless already consumed. At half-minute intervals during the test, readings are taken of the loss in weight as indicated by the pointer on the chart and of the temperature at the top of the tube as shown by the pyrometer *Pr*, which is attached to the thermocouple *Th*. If desired, the actual loss in weight of the specimen at each reading can be readily calculated from the weight of the specimen before test and the percentage-loss readings.

The loss in weight and the temperature data taken at half-minute intervals can be plotted as curves which afford excellent

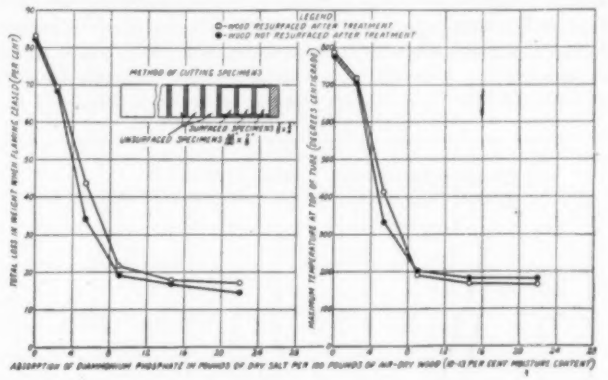


FIG. 9 COMPARISON OF RESULTS ON SURFACED AND UNSURFACED BOARDS OF SOUTHERN YELLOW PINE TREATED WITH DIAMMONIUM PHOSPHATE

(Each plotted point is based on 16 to 20 specimens, cut from four boards.)

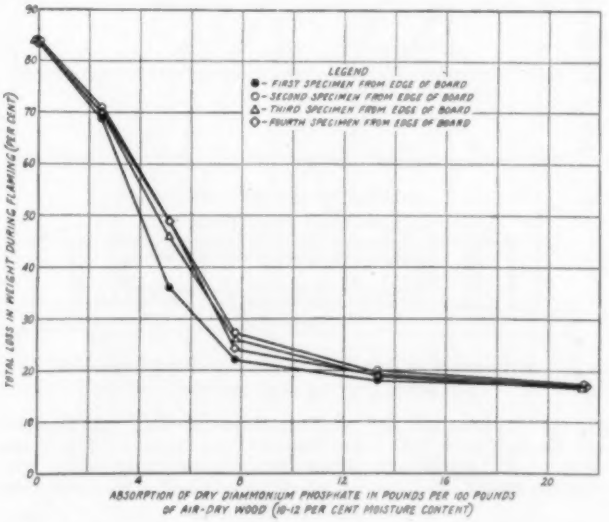


FIG. 10 EFFECT OF POSITION OF SPECIMEN IN TREATED BOARDS ON RESULTS OF TESTS. DIAMMONIUM-PHOSPHATE TREATED MATERIAL

(Each point represents eight specimens cut from eight different boards, four each of Southern yellow pine and yellow birch.)

means of comparing the results obtained from different specimens. The results of tests on individual specimens untreated and treated with different amounts of a fire-retardant salt are shown in Fig. 4 and illustrate typical curves obtained by the fire-tube test.

USE OF THE FIRE TUBE IN MEASURING FIRE RESISTANCE

With the fire-tube apparatus perfected to the point where it was considered a useful measure of fire resistance, tests have been undertaken to measure the fire resistance of wood treated with various fire-retardant chemicals. In Figs. 5 and 6 are shown the results of tests on Southern yellow pine and yellow birch boards treated with various amounts of diammonium phosphate. Nominal 1-in. boards 7 to 8 in. in width and 6 ft. long of each species were treated with the aim of obtaining absorptions of about 1, 2, 3, 5, and 7 to 8 lb. of chemical per cubic foot of wood.

The lumber was selected so as to obtain all sapwood in the pine and as much as possible in the birch. The material was further selected for density, and only the boards within an intermediate range of density for each species were used. The boards were pressure-treated under conditions that were intended to give complete impregnation of the chemical through the boards. Four boards were used for each treatment with each species and salt. Four or five specimens were tested from each board. The boards were $^7/_8$ in. thick when treated, and the parts from which specimens were cut were surfaced approximately the same amount on both sides to $^3/_4$ in. before testing, as shown in Fig. 3*A*.

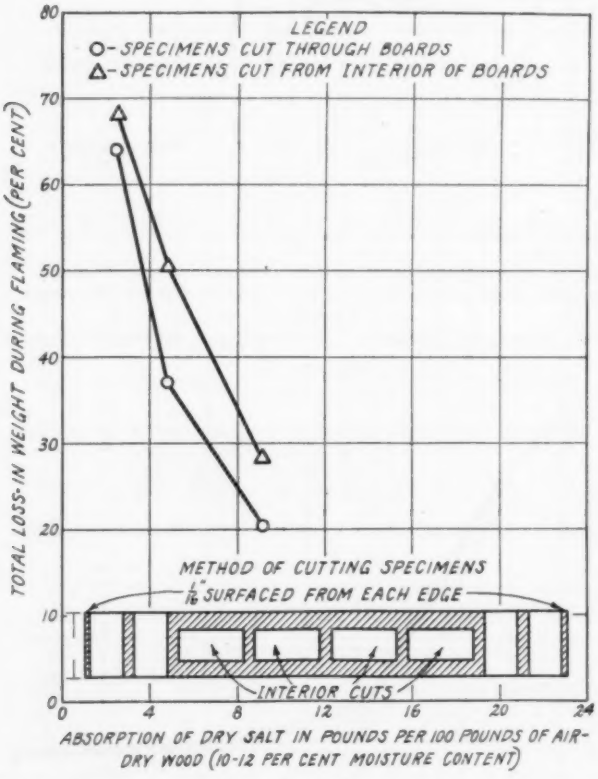


FIG. 11 COMPARISON OF THE FIRE RESISTANCE OF THE INTERIOR AND EXTERIOR OF SOUTHERN YELLOW PINE BOARDS THOROUGHLY IMPREGNATED WITH DIAMMONIUM PHOSPHATE

(The two plotted points for each absorption are based on the same number of specimens.)

The losses in weight at the time flaming ceased and the maximum temperatures developed at the top of the tube during test are plotted in Figs. 5 and 6 against absorption of salt in pounds per 100 lb. of air-dry wood for each specimen tested. The points on the graphs show the differences obtained with different specimens and different boards. It is very evident that the greatest differences in results in individual specimens and boards occurred in the region of 4 to 7 lb. of salt per 100 lb. of wood. Within this border-line range of absorptions the degree of effectiveness of the salt was just sufficient that the burning of the specimen might stop at the time the gas flame was removed or very shortly thereafter, giving a small loss in weight, or it might continue to burn slowly for some time, showing eventually a larger loss in weight. For material untreated or lightly treated (3 lb. or less per 100 lb. of wood) and for treatments of 5 lb. or more per cubic foot, the results are reasonably consistent. The results, obtained by averaging the four untreated boards and the four boards of each wood receiving similar absorptions, are shown in Fig. 7. It is quite evident that a similar degree of effectiveness was obtained in the two woods when the same percentage of diammonium phosphate per 100 lb. of air-dry wood (10 to 12 per cent moisture content) was used.[6]

The comparisons thus far made between the two woods and the different absorptions of salt have been on a basis of the total loss in weight when flaming stopped and on the maximum temperatures developed during test. From the data taken comparisons may also be made at other times during test, as for example, at the end of 2 min. In Fig. 8 the average losses in weight and maximum temperatures at the end of 2 min. of test are shown for diammonium phosphate and the two kinds of woods. Data shown in Fig. 8 are from the same specimens shown in Fig. 7.

In the test the ignition flame comes directly in contact with the lower one-fourth of the specimen, and that part of the specimen is largely destroyed even in treated wood. In the case of effectively treated material the actual loss in weight depends very largely upon the density of the wood in contact with the flame. For example, if a specimen weighs 100 grams and loses one-fourth, the loss is 25 grams, whereas in a 200-gram specimen the loss would be 50 grams. Two specimens of different weights therefore may show very different actual losses in weight, although one may not spread the flame any farther than the other. Percentage loss shows quite clearly the extent of burning beyond the ignition flame, irrespective of the density of the specimens.

EFFECT OF POSITION OF SPECIMEN IN THE BOARD

Surfaced and Unsurfaced. The results so far presented and discussed relate to nominal 1-in. boards impregnated with fire retardant throughout, dried to an air-dry condition, and then surfaced before test. Approximately $^1/_4$ in. was removed from the edges and $^1/_{16}$ in. from each of the faces before cutting the specimens (Fig. 3*A*). In order to determine the effect of the surfacing on the results, tests were made on adjacent surfaced and unsurfaced portions of Southern yellow pine boards. The unsurfaced portion came from approximately the center of the board, while the surfaced part was cut from one side.

The results of the tests are shown in Fig. 9. The average losses in weight were consistently higher in the surfaced treated boards than in the unsurfaced boards. The maximum temperatures developed during test were higher for the surfaced boards except for the three highest absorptions, where the unsurfaced boards gave slightly higher temperatures. In general, the results indicate that the concentration of salts was somewhat higher near the surface than in the interior of the boards and that surfacing had removed some of the most effectively treated material.

A comparison was also made between the first, second, third, and fourth specimens tested from each board (see Fig. 3*A*). The data for birch and Southern yellow pine, shown in Figs. 5 and 6, were averaged for the first specimens, second specimens etc., and the results are shown in Fig. 10. Although $^1/_4$ in. was cut away from the edge of each board before cutting the specimens, the first specimen still showed slightly greater fire resistance in the treated boards than the other specimens. No consistent difference was evident between the second, third, and fourth specimens.

A few tests were also made to compare specimens cut from the interior of boards with similar specimens cut near the edges. Boards of Southern pine treated with diammonium phosphate were used, and the specimens were cut as illustrated in the sketch in Fig. 11. As the curves indicate, the specimens cut from the interior of the board showed considerably less fire resistance than

[6] A more complete discussion of results obtained to date with the fire-tube apparatus is presented in the 1930 Proceedings of the American Wood Preservers' Association in a paper entitled "Fire Resistance of Wood Treated With Zinc Chloride and Diammonium Phosphate," by Hunt, Truax, and Harrison.

those cut through the board from face to face. Although the results for the first and second specimens cut from the edges were averaged, the first specimens showed slightly higher fire resistance (less loss in weight) than the second specimens. This indicates that there is a considerable difference in fire resistance between the center and the outside of thoroughly impregnated boards.

Moisture Content of Wood

Since the moisture content of wood is known to be a factor in the inflammability of wood, some tests were made to determine its effect in the fire-tube test. Matched specimens, cut from the same boards, were exposed to a temperature of 140 deg. fahr. (humidity undetermined) and to a temperature of 80 deg. fahr. at relative humidities of 30, 60, and 90 per cent until approximately constant in weight. These conditions brought the untreated wood to moisture contents of about 1 to 2, 6 to 7, 11 to 12, and 22 to 23 per cent, respectively.

The results of the tests are shown in Figs. 12 and 13. In Fig. 12 losses in weight and temperatures are plotted against time of test. It is evident that the moisture content affects the rate of burning in the untreated and the lightly treated material. It has less effect in the heavily treated material. In Fig. 13 the average results obtained with different absorptions of diammonium phosphate are shown. The total losses in weight at the time flaming ceased and the maximum temperatures are plotted against absorption. The differences in moisture content had the greatest effect in the range of 3 to 10 lb. absorption of dry salt per 100 lb. of wood. While the rate of burning was distinctly slower for material at a higher moisture content in the case of untreated or lightly treated wood (Fig. 12), the total loss and maximum temperatures are nearly the same as for the material with a lower moisture content (Fig. 13). Consequently, the results are less liable to be affected by a difference in moisture content if total losses in weight when flaming ceases are taken as the measure of the fire resistance than the losses at some earlier time during tests, such as 2 min.

Other Factors Affecting Test

Other factors, including the density of the wood, the presence of heartwood and sapwood, especially in some species, the presence of oils, resins, and the like, and the depth of penetration and uniformity of absorption of the fire retardant, are of importance in testing fire-resistant wood. Although information is inadequate on the influence and importance of these factors, some information is available on all of them. Density affects the rate at which a piece is destroyed by fire and the amount of heat evolved.

The presence of heartwood in otherwise all-sapwood material affects the test results. This has frequently been observed and may be due to a smaller proportional amount of fire retardant, incomplete impregnation, or to the wood itself being different in fire resistance. The difficulty of impregnating the heart-

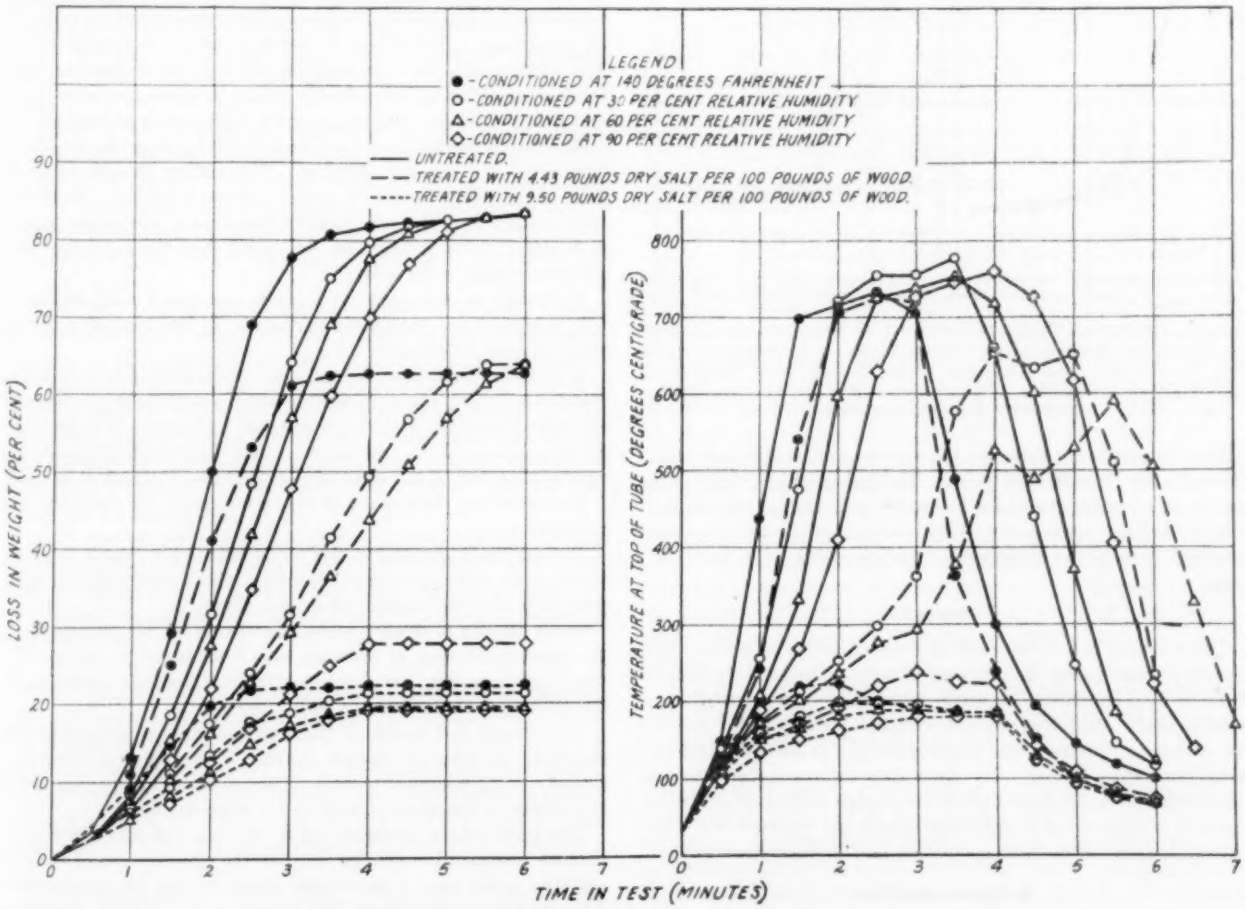


Fig. 12 Effect of Moisture Content of Wood on Rate of Burning. Tests Made on Southern Yellow Pine Untreated and Treated With Diammonium Phosphate

(Each point on untreated wood is an average of twelve specimens and on treated wood of three specimens.)

wood of certain woods with water solutions is well known. It is also generally known that wood which contains considerable quantities of oil and pitch ignites and burns readily. Differences in inflammability of some species when untreated are measurable on the fire-tube apparatus.

It is felt that the fire-tube test will contribute materially in

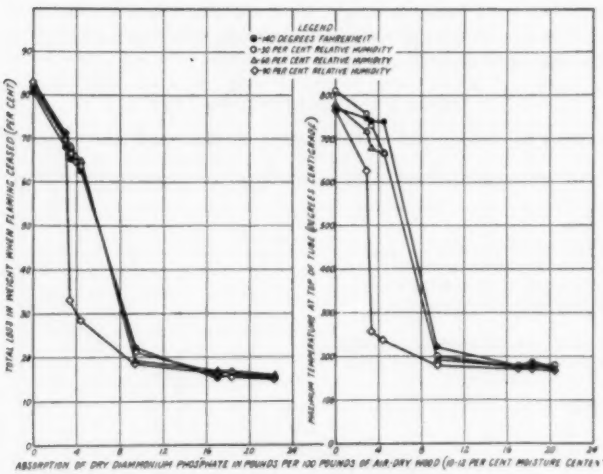


FIG. 13 EFFECT OF MOISTURE CONTENT ON TOTAL LOSS IN WEIGHT AND MAXIMUM TEMPERATURE. TESTS MADE ON SOUTHERN YELLOW PINE UNTREATED AND TREATED WITH DIAMMONIUM PHOSPHATE
(Each point on untreated wood is an average of twelve specimens and on treated wood of three specimens.)

further attempts to evaluate the factors and conditions which affect the fire resistance of wood. The test promises to be useful also as an acceptance test for fire-resistant wood for certain purposes as well as a means of working out some of the problems confronting those in the business of treating wood with fire retardants.

SUMMARY

The fire-tube test is believed to measure more accurately and in more definite terms the property of wood to resist the spread of flame and to contribute to an increase in temperatures than is possible under other test methods commonly employed. Results are shown to illustrate the significance of the fire-tube test and certain variables of test. By controlling known factors the test results can be duplicated with a reasonable degree of accuracy. The test is regarded as a useful and significant measure of the fire resistance of wood both in inspection and investigative work.

ACKNOWLEDGMENT

Acknowledgment is made of the financial assistance of the National Lumber Manufacturers Association in this study of the fire resistance of wood.

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Discussion

FRANK P. CARTWRIGHT.[7] In my present capacity, and as Chairman of Sub-Committee II of A.S.T.M. Committee C-5, which is charged with developing a standard form of test for fire-retardant treated wood, progress in treatment effectiveness, and in methods of measuring, it has been of intense interest for several years. The holding of such a meeting on the subject of fire-retardant treatments seems to indicate that actual progress has been made and that it is being recognized by the engineering profession.

Mr. Storm has hit the proper keynote in terming the results of treatment as "Firesafe" lumber. The author should define a little more clearly what "firesafe" lumber must be. Studying the question from the viewpoint of fire control and public safety in building codes, it has been concluded that there are four important criteria of fire safety:

1 Firesafe wood should not support nor spread combustion.

2 It should not contribute materially to the heat of a fire in which it may be involved.

3 Used in doors, partitions, floors, for protection of structural members, or for other purposes for which a definite fire-resistance rating is prescribed, firesafe wood should be capable of sufficiently uniform control of the treatment so that dependable performance can be expected of the structural assemblies in which it is used.

4 It must be permanent in character under all ordinary use conditions.

It would be interesting in this connection if Mr. Storm can give the amount and character of chemicals which were put into samples 6805 to 6807 mentioned in the paper.

Other criteria of treated wood, mentioned by Mr. Storm, such as appearance, ease of working and finishing, hydroscopicity, wear resistance, etc., are also important, but from the viewpoint of fire resistance these four are really important.

The second and fourth of these criteria almost automatically eliminate painting or surface coating from available methods, since a coating is subject to removal and does not in any case affect the ability of the wood to add to fire temperature.

The third makes necessary some test method which will give definite quantitative results, so that the effectiveness of treated material going into a structural assembly can be anticipated. This yardstick of treatment Mr. Truax's method of test provides. The tendency of the wood to burn under applied heat, and thereafter to support its own combustion in a heated enclosure, is clearly and quantitatively shown (see left half of Fig. 4). Since the curves at the right of Fig. 4 indicate maximum tube temperatures against time, the area under each curve and above the horizontal line representing tube temperature without the specimen may be considered a fair measure of the heat which lumber so treated will contribute to a fire in which involved. Mr. Truax unfortunately has not shown this line, but it would run across the chart at an ordinate of 185 deg., well above the combined temperature of flame and specimen. In other words, well-treated wood not only does not contribute to the heat of a fire in which it is involved, but it subtracts from it.

As to the practical uses of fire-retardant treated wood, from a

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safety viewpoint it would seem that the use of fire-retardant treated wood for molding, trim, flooring, and other purely finish purposes in a building of reinforced concrete or protected steel construction is immaterial. A survey of office floor loads in a large New York City building some years since showed an average of 11.6 lb. per sq. ft. and in many cases exceeding 30 lb. per sq. ft., very largely of combustible material. In loft buildings the proportion of combustible contents is much greater. The addition of perhaps 3 or 4 lb. per sq. ft. of wood to the total has little effect on fire temperatures.

When it comes to wood for partitions, doors, shaft enclosures, or other devices for controlling the spread of fire, or to the use of treated wood as fire protection for structural members, of wood or other materials, the possibilities are endless. The building-code requirements of half a hundred cities are so drawn at this date that a door of fire-retardant treated wood which demonstrated a definite period of fire resistance would find acceptance automatically.

Treated scaffolding plank, mentioned by Mr. Storm, represents an example of use which confers actual fire safety. The boxing in of columns and beams in heavy timber construction and of important structural shapes in steel-framed industrial buildings probably will add from 50 to 100 per cent to their safety in case of fire, and may eventually come to be a more or less general practice.

When this time comes, and perhaps even in the near future, the need will be felt of two or three standard grades of treatment, adapted to the purposes for which the lumber will be used, as preservative treatments are now adapted to conditions of service. These degrees of treatment will need to be identified by distinguishing marks, behind which those treating lumber can stand; and for testing and control of treatment quality, a definite, quantitative method of test, such as Mr. Truax's method provides, will be necessary.

The fire-retardant possibilities of various well-known chemicals are being investigated systematically, and it is easily conceivable that treatment for this purpose will soon become a customary activity of concerns now devoting themselves solely to preservative treatment.

PROF. HENDERSON.[8] The subject is of importance to engineers and lumbermen because of the coming in of so-called substitutes. These were brought in primarily because they were thought to be fireproof or fire resistant. These demonstrations have brought out the fact that wood can be made more or less fireproof. There seems to be quite a fire resistance anyway, and it is going to overcome many of the supposed detriments to the use of wood.

DR. WINOGRADOW.[9] The writer would like to discuss one point about the temperatures, relating to Fig. 4. One item is not taken into consideration, and that is the elongation of the flame at the moment when the flame comes in contact with the specimen which hangs in the tube. It has been observed in experiments that at the moment a specimen is in contact with the flame, even a specimen of asbestos or porcelain, it is combustible, and there is an elongation of the flame sometimes over 50 per cent. So the longer the flame the closer it is to the top of the tube. There is an increase of temperature due to this elongation occurring automatically. It seems that this should be taken into consideration. It is suggested that in this case they measured the temperature on the top of this cylinder without the specimen and they found it to be about 180 deg. cent. It is suggested that they place a stick of asbestos and measure under this condition, and then there may be a different result. There will be a higher temperature at the end at the top of the tube and a lower temperature in case there is placed a highly saturated specimen, because the heat will be absorbed or transferred. . The calories will be transferred into work by the decomposition of the chemicals. So the curve will probably run a little differently. At the start it will be lower and it will go up.

MR. TRUAX. As to the points that Mr. Cartwright and Dr. Winogradow raised in reference to the temperature and the calibration of the apparatus as to the height and flame, the authors would say that, before we start a test, we calibrate the flame. We adjust the flame to get a height of 11 in. plus or minus $^1/_2$ in., and a temperature of 1000 deg. cent. plus or minus 25 deg. cent., or about 182 deg. fahr. That brings the temperature at the top of the tube to approximately 180 deg. cent.

Referring to Fig. 4 it may be noticed that in burning the specimens containing 5 lb. and over of salt, the temperature did not reach the calibration temperature of 180 deg. cent. That confirms the point that Dr. Winogradow made that there is an absorption of heat. There undoubtedly is some burning of gas, but also there is an absorption of heat. In other words, we did not build up temperatures as a result of any combustion which may have occurred.

With reference to the height of flame and elongation of the flame, we calibrate the flame out of the tube, and we know that it does spread when applied to the specimen. It is suspected that the spread on the specimen will be related to some extent to the inflammability of the material. It is not quite seen, however, how we could standardize that in the test method—that is, take account of the elongation of the flame. So long as we have a standard height flame, a standard temperature flame, and a standard temperature at the top of the tube to begin with, we are subjecting untreated specimens and the various treated specimens to substantially the same conditions.

We have a range in temperature; at the bottom of the specimen the temperature may be regarded as fairly severe, and at the top of the specimen the temperature is very close to the ignition point of wood if exposed for a long period. That was pointed out in the early part of the paper. The work of Prince and of others indicates that wood ignites eventually at about 180 to 200 deg. cent.

We believe we have a set of conditions in the fire tube which enables us to measure the property of wood to spread flames and to build up temperatures by combustion.

RALPH H. MANN.[10] I would like to point out the fact that all of the tested sticks which had been impregnated were sticks of sap timber, that portion of the wood which most readily will take up treatment. Is there any ready method by which the ordinary lumberman, contractor, or engineer can tell the difference between long-leaf pine and ordinary Southern pine.

MR. TRUAX. We selected the sapwood so that we could make certain of complete impregnation in the timber. If one is going to study the relationship between the amount of chemical in the board and the effectiveness, there must be a uniform distribution in each piece. There are many species in which it is difficult to thoroughly impregnate the heartwood, and the heartwood was purposely avoided for that reason.

I believe there is no way by which a lumberman can identify pine by ordinary vision and inspection and be sure whether a stick is longleaf pine or shortleaf pine.

MR. HARMON.[11] I would like to ask Mr. Truax what are the shortcomings of the present timber? Have you any results of

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[11] Bureau of Buildings, New York, N. Y.

the crib and shavings test conducted at Columbia University?

MR. TRUAX. We have tested treated material by the New York tests and the firetube test. Our principal objections to the New York tests are that they leave too much to the judgment of the operator; for example, in the shavings test, as to the character and quantity of the shavings. The directions state that they should be packed moderately, but in that respect variations will be very great. Consequently, different results will be obtained on the same material in different testing laboratories. Another point is the thickness and form of shavings. It is almost impossible to get uniform shavings from different species of wood. Without uniform shavings the test cannot be duplicated.

I do not believe one can duplicate the New York test closely, with different operators and in different testing laboratories. Our test rather clearly indicates that there is a distinct relationship between the amount of chemical in the wood and its effectiveness. With the New York test we were unable to get a consistent relationship.

MR. STORM. I would like to ask Mr. Truax if any attention has been given to the corrosive effect, if any, of the chemicals used—the ammonia and zinc chloride?

MR. TRUAX. Chemicals vary enormously in corrosive action. Previous tests by Prince indicate that some chemicals are distinctly objectionable from a corrosion standpoint.

MR. STORM. Could you tell about the affinity of those chemicals to moisture?

MR. TRUAX. We have been making moisture-content determinations along with the fire-testing work, and we find that there is some additional moisture or something driven out at the time the moisture-content determination is made; whether it is moisture or whether it is chemical we do not know. With diammonium-phosphate there is not much difference from untreated wood. With zinc chloride there is a little higher moisture-content than one would expect from untreated wood.

MR. STORM. How would the absorption of a piece of wood so treated compare with the absorption in any given humidity of an untreated piece of wood—I mean with these two chemicals, zinc and diammonium-phosphate?

MR. TRUAX. The diammonium-phosphate is about the same as untreated wood. Zinc chloride is slightly higher than untreated wood.

MR. STORM. Do you feel that those chemicals would be practical as a treatment in lumber from that standpoint?

MR. TRUAX. Zinc chloride has been used for a long time in the wood-preservation industry. It is one of the principal chemicals used to treat wood for decay resistance. It does have considerable fire resistance. Whether it is practical to put as much zinc chloride into wood as one would need to get high fire resistance, I would not attempt to answer. It may be that the large amount of chemical that is necessary to get high fire resistance would injure the wood or bring about other disadvantages that would be objectionable.

ERNEST F. HARTMAN.[12] Within the course of a month, a paper on fire resistance of wood was presented before the American Wood Preservers' Association, an editorial on fireproofed wood appeared in *Wood Preserving News*, and now comes this valuable contribution on measuring the fire resistance of wood. Considering the scarcity of literature of the subject, this would seem to indicate considerable interest, and as the operator of the 35-year old Bachert process of fireproofing, this is indeed gratifying.

It is but proper to state that common acceptance of the designation "fireproofed wood" is here used in that sense and with a full recognition that the terms fire-retardant, fire-resistant, and non-inflammable are more suitable.

Flameproofing is considered as the partial impregnation of wood sufficient to withstand external flame. Fireproofing demands the complete penetration of the chemicals of the very core of the wood.

It should be noted that the reprint in Appendix 1 of Mr. Storm's paper does not cover the New York Building Department rules now in effect and fails to include the requirement adopted last March that, before testing, all samples must be oven-dried at 140 deg. fahr. to a constant weight.

Acknowledgment is made of the compliment paid by Mr. Storm that the old fireproofed wood has retained its efficiency and that records show this to be true after more than 30 years. It is on the development of this successful process that the writer has been working in an endeavor to secure progress by evolution. He is not a lumberman in the sense that he is not interested directly or indirectly in the sale of timber, lumber, or wood. The subject of fireproofing wood is approached as an engineering problem dealing with a structural material. The distinction between science and engineering is a difference both in purpose and method; it is the sharp contrast between dream and attainment. It is the engineer who is responsible for the development of the modern equipment used in wood impregnation. The forester, the pathologist, and the chemist must all collaborate, and so it is that separate chemical and plant laboratories are maintained as a matter of industrial research. Thus it has been possible to develop treatments satisfactory for what are called refractory woods, such as American walnut, white oak, etc. On one job for interior trim there may have teakwood, French walnut, and marmut. Thus, library and laboratory are necessary to provide answers to questions on suitable methods of treatment. Often the writer's experience of 30 years in the field of wood impregnation finds itself impotent. Those interested in the grouping of woods for treatment will find much valuable experience recorded in the proceedings of the American Wood Preservers' Association. Wood-using industries will likely find it to their advantage to utilize the accumulated experience of the more than a hundred-year-old wood-preserving industry, especially since the equipment now available will answer for all treating requirements for fireproofing.

Being the first to commercially flameproof scaffolding used in New York City is an acknowledgment that the writer favors the partial impregnation of wood. Here the condition of a short mechanical life makes possible the use of cheaper chemicals than are used in fireproofing to New York City Building Department requirements. Chestnut contains considerable tannin and so discolors the treating solution. Certain other woods also discolor the solution, and in consequence proper plant equipment calls for a considerable number of storage tanks for the varying solutions required for different woods or for different treatments.

In discussing the paper on "Fire Resistance of Wood" recently at Seattle, the writer took occasion to call attention to the vital importance of the chemistry of wood to the fireproofer. This will frequently necessitate changes in the chemicals. Of the various constituents of wood, those with the greatest calorific value demand first consideration. Lignin, which is incrustated material, possesses an excess of carbon and hydrogen and is soluble in acids. Compared with oxygen its combustion produces more heat than that of cellulose. Since lignin is present in large quantities in hardwoods and more abundant in the heart than in the sapwood, it will be apparent that thorough chemical treatment of the heartwood is absolutely essential if New York City Building Department requirements are to be met. Ingberg gives the calorific value of cellulose as 7570 B.t.u. per lb. In the case of Douglas fir the figures would be 10,550 B.t.u. per lb. for components other than cellulose.

[12] President, Protexol Corporation, Kenilworth, N. J.

Success in producing stainless fireproofed finished oak flooring that under proper humidity conditions in new buildings does not shrink or swell first induced experiments with milled stock and moldings. The drying of such stock produced new questions which are still being investigated. A fair number of jobs have been run through successfully, and these have included glued-up stock. This, it is hoped, will materially reduce the cost to the woodworker, and it is also hoped, by eliminating the difficulties of working fireproofed wood, to secure good will where today most woodworkers consider fireproofed wood an abomination that they must put up with because of the law. Incidentally, the writer does not favor legislation as a means of increasing a demand for fireproofed wood. A healthy demand can result only from supplying a need, and no industry can prosper that must depend on subsidy or legislation for an existence.

The greatest objection to fireproofed wood from architects has resulted from the staining of wood or the causing of discoloration. To overcome this prejudice of many years' standing will require much educational work, and exhibits of fireproofed wood should not be neglected whenever opportunity offers. Otherwise no prejudice has been found anywhere. The fact is that the public has not been informed by the fireproofer, and trade literature is practically unknown.

As the writer views the requirements of industry, it will be necessary to combine wood preservation with suitable flameproofing. If by so doing, there can be a reduction of the fire risk and the securing of consideration from insurance companies in a lower rate, it will be possible to maintain for wood its position as the best insulating roofing material. It is, however, not sufficient to accomplish this result unless it is at a cost somewhere near what is being paid at present for straight wood-preserving treatments. This, then, requires that there must be a one-movement process, since two movements add materially to the cost, as the wood preserver learned long ago when discarding the Wellhouse process. The chemist must supply chemicals of sufficient toxic strength with known fireproofing chemicals that will readily remain in solution during treatment, but which will combine and become insoluble after the watery menstruum dries out. The toxics to be used must be well known if one would avoid having to demonstrate their efficiency by the test of time. The flameproofing can be demonstrated, though its permanence may be questioned. It is along these lines that the writer is conducting research and experiment.

Messrs. Truax and Harrison have made a valuable contribution and have given another and a most accurate method of determining relative values in fireproofing. Peter Lochtin in 1893 probably gave the first comparable data. During 1914, when testing the inflammability and combustion loss of treated timber with engineers of the New York Connecting Railroad, the writer employed a sand bath in a closed muffle and in the absence of direct flame. At Vancouver, B.C., Banfield and Peck in 1922 used an electrical furnace.

While of inestimable value in the laboratory, the method suggested does not lend itself to the testing of commercial requirements of either flameproofed or fireproofed wood, since many of the sizes that occur will not permit of securing a sufficiently long test piece. It appears desirable to have information available on the behavior of the sample at comparatively low and high temperatures if one is to consider the temperature of a burning building at the values set by Woolsen and Weiss—i.e., 1700 deg. fahr. There therefore need be no concern over the temperature obtained with a welding torch and which, after all, being fed by air, does not reproduce any ordinary method of ignition. An acceptance test to evaluate flameproofed wood is indeed badly needed. It would possibly prove of interest to have comparative data on treatments for air-dried and kiln-dried material.

It may be worth while to record the information obtained from the New York Building Department tests.

The shavings test is intended to prove that wood properly fireproofed will not support flame, and in case flame should appear it should be of short duration and die out without materially consuming the shavings outside the flame area of the burner. The temperature for this test is approximately 800 deg. fahr.

The crib test at 1200 deg. fahr. measures the tendency of the material to transmit combustion. It indicates the action of the burning wood in contact with other wood and the tendency of the material to spread flame.

The timber test at 1700 deg. fahr. is important in determining the structural conditions. It determines the degree of incombustibility of the material, but is not conclusive as to its inflammability.

Summarized, then, the shavings test shows ignition, the crib test communication, and the timber test strength of the wood.

The veneer or splinter test has been discontinued. This at 1000 deg. fahr. aimed to determine the degree of incombustibility of veneering materials. This test was made on a hot plate, and only charring without flame should occur. It appears desirable because of the fact that conflagration may expose wood for some time to a strong heat without direct contact with flame; in fact, it may cause temperature equal to dry distillation without flame contact.

One other thought in this connection is suggested by fire-protection engineering. Due consideration must be given to the fumes and smoke given off by burning materials in order to safeguard the life of the fire fighter. Means for determining the kind and quantity of the fumes and smoke are therefore necessary. Again, smoke explosions are not uncommon and must be guarded against.

These comments are offered in the hope that they will stimulate further study and investigation.

WDI-52-5

End-Matching, Edge-Jointed and Surface-Laminated Wood Parts for Auto-Body Building

By G. G. WHITE,[1] DETROIT, MICH.

Advantages and savings from cutting lumber to final dimensions at the point of supply are discussed in this paper. Freight charges on waste and on the moisture removed in kiln drying are saved. In addition a lower grade of lumber can be used, and by cutting to size and shipping in bundles, the cost of handling is reduced and much less storage space is needed. The author describes various manufacturing processes used in the construction of wood frames for automobile bodies. Use of laminated woods has done much to conserve the timber supply because species of woods not previously used can be worked satisfactorily.

CONSTRUCTION of the wood frames of automobile bodies and methods of procuring this material have passed through some radical changes within the past four years. In 1929 the management of a large body plant, in studying costs, saw that the average waste in cutting body parts from all thicknesses of lumber between 1 in. and 3 in. was 35 per cent. Realizing that they had paid the freight on this waste, the question arose, "Why pay freight on 350 ft. of lumber and then burn it?" Also each 1000 ft. of air-dried lumber contains approximately 700 lb. of water that is removed in kiln drying. This weight together with that of the lumber scrapped amounted to 1925 lb. per 1000 ft. on which freight is paid. At 40 cents per 100 lb. this amounts to $7.70 that could be saved. From this calculation was born the idea of operation in the South, in the heart of lumber supply. The saving in freight added to low labor cost in the South made the idea very attractive.

A small plant was started in Arkansas and operations at this plant proved the calculations correct, and also disclosed other cost-reducing features not considered at first. It was found that a lower grade of lumber could be used. The lumber was kiln dried, cut to size, and shipped in bundles of convenient size for handling. This method effected a considerable saving in storage space, which is always at a premium in a body plant. Material handling costs were reduced by 70 per cent. Material received in this manner can be placed on mill trucks in the railroad car and taken direct to the machine room.

Hardwood Should Be Cut to Dimension Sizes

It is not possible to argue logically for the cutting of hardwood into board form for re-manufacturing operations. It is undoubtedly true that softwood was originally cut into boards for structural purposes where long lengths were the units of building. Apparently manufacturers of hardwood followed the procedure of the softwood manufacturers, and practice and precedent have carried forward the producing of hardwood lumber in board form.



Fig. 1 Lumber Storage at a Detroit Body Plant

There is no practical reason why hardwood logs cannot be sawn with reference to the final dimensions required for re-manufacturing operations, at least to some multiple of the same, or with some definite relation to the eventual sizes. It is usually more convenient to kiln dry and handle in multiple sizes. There seems to be no logical reason, however, for preserving the standard board lengths, widths, and thicknesses now in use.

A small part of a typical dimension specification for the lumber required for a medium-price sedan body is given in Table 1 preceded by a brief description of the grades. Table 2 is a recapitulation of the preceding table and shows in the right-hand column the proportion of the various final lengths that are required, and it is perfectly obvious that the large proportion of short lengths gives a better basis of sizing than the conventional board standards.

Ratio of Thickness Values

Several dimension manufacturing companies came into the field and the cost item was attacked in earnest. The first thing considered was the high prices paid for "thick lumber," meaning 2½ and 3 in. thick, which usually sells for $15 to $25 more per 1000 ft. than 1 in. thickness. Taking a lesson from the veneer manufacturers, experiments were started to use 1-in. lumber laminated to take the place of thick lumber. Most of the body engineers were not in favor of using laminated stock for various reasons, but after many experiments and laboratory tests

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[1] Vice-President, Wood Parts, Inc. For seven years Mr. White was engaged in general construction engineering work for railroads, coal mines, iron mines, and buildings. For five years he was lumber superintendent of the Chrysler Corporation in charge of lumber buying, export box requirements, and assistant superintendent of the body plant.

Contributed by the Wood Industries Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

TABLE 1 LUMBER SPECIFICATIONS FOR MODEL AA SEDAN

Part no.	Rough size solid 4/4 ×	Mat. as rec'd	Pcs. per body	Pcs. per unit	Footage per body	Grade
82732	1 1/2 × 43	P.F.	1	1	0.373	B
82835	1 1/4 × 23 1/2	P.F.	4	1	0.816	B
82768	1 × 23	P.F.	2	1	0.319	B
82731	1 × 18 1/2	P.F.	2	1	0.256	B
69309	1 × 25	P.F.	2	4	0.087	B
69363	1 1/8 × 13 1/2	P.F.	2	8	0.032	B
82751	2 1/4 × 17 1/4	P.F.	2	1	0.539	DB
82752	4 3/8 × 23	P.F.	2	1	1.397	EB
82754	1 3/4 × 18 1/2	P.F.	4	4	0.225	B
82717	3 7/8 × 45 1/2	P.F.	2	1	2.449	EB
82719	4 7/8 × 17	P.F.	2	1	1.151	EB
82749	4 7/8 × 44 1/2	P.F.	2	1	2.704	EB
82716	2 3/4 × 21 1/2	P.F.	2	2	0.411	B
82720	3 1/4 × 11 3/4	P.F.	1	1	0.265	DB
82723	2 1/4 × 44	P.F.	1	1	0.688	DB
69062	1/4 × 41 1/2	P.F.	1	1	0.036	A
82737	3 1/2 × 43 1/2	R.D.	1	1	1.057	A
82734	4 1/2 × 47 3/4	R.D.	1	1	1.485	A

Abbreviations: P.F. = Planed faces, R.D. = Rough dimensions.

TABLE 2 BOARD FEET OF VARIOUS LENGTHS AND THICKNESSES

Lengths	Thicknesses 4/4 in.	6/4 in.	8/4 in.	10/4 in.	12/4 in.	Total
Under 24 in.	12.945	4.876	3.642	0.638	6.070	28.171
25 to 36 in.	23.180	14.074	7.081	3.387	——	47.722
37 to 48 in.	21.395	7.523	28.232	2.500	6.152	65.802
49 to 60 in.	5.734	2.208	2.972	3.819	——	14.733
61 to 72 in.	——	——	——	——	——	——
73 to 84 in.	——	5.659	——	——	——	5.659
85 to 96 in.	4.949	——	——	——	——	4.949
97 to 108 in.	——	——	17.876	——	——	17.876
over 108 in.	——	——	——	——	——	——
Total	68.203	34.340	59.803	10.344	12.222	184.912

PERCENTAGE OF VARIOUS LENGTHS AND THICKNESSES

Lengths	Thicknesses 4/4 in.	6/4 in.	8/4 in.	10/4 in.	12/4 in.	Total
Under 24 in.	7.1	2.4	2.0	0.4	3.3	15.2
25 to 36 in.	12.5	7.7	3 .8	1.8	——	25.8
37 to 48 in.	11.6	4.1	15.2	1.4	3.3	35.6
49 to 60 in.	3.1	1.2	1.6	2.0	——	7.9
73 to 84 in.	——	3.1	——	——	——	3.1
85 to 96 in.	2.7	——	——	——	——	2.7
97 to 108 in.	——	——	9.7	——	——	9.7
Total	37.0	18.5	32.3	5.6	6.6	100.0

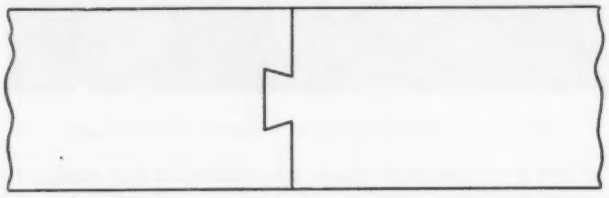


FIG. 2 DOVETAIL EDGE JOINT MADE ON A LINDERMAN MACHINE

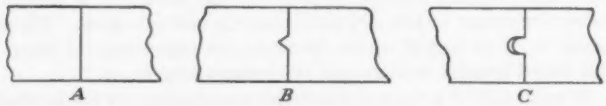


FIG. 3 THREE TYPES OF JOINTS—*A*, PLAIN JOINT; *B*, V JOINT; *C*, TONGUE AND GROOVE JOINT

this material was approved for use by most of them. This approval also included the use of oak, a wood not used extensively by body builders, because they had not been able to dry thick oak with any degree of speed, oak taking approximately 80 per cent more time in the kilns than other species of wood.

Oak 1 in. thick can be purchased at approximately 40 per cent of the cost of 2-in. Southern lumber suitable for body work. The 1-in. oak can be kiln dried to 6 per cent moisture content in approximately 8 days. The use of 1-in. lumber laminated enables one to more than double the output of the kilns.

METHODS OF MANUFACTURING

The lumber should be kiln dried to between 5 per cent and 6 per cent moisture content. Care should be exercised in stacking the lumber on kiln trucks to see that plenty of stacking sticks are used to prevent warping. Straight lumber is essential to secure proper lamination. The lumber passes from the kilns to dry storage for tempering or equalizing, and should not be cut until it has been out of the kilns at least 3 days. This gives it time to equalize any strains or stresses that may have developed in kiln drying. It is then taken through cut-off and rip saws, where it is cut to length and edges are straightened where necessary. It is then sized, i.e., passed through a single surfacer set at 15/16 in., which gives the lumber one surfaced side and a uniform thickness. At this point two methods are used to make up the blanks for laminating—first, linderman machine; second, edge-gluing on rotating glue clamps. These methods are as follows:

1 The lumber is put through the linderman machine, which makes up the blanks using a glue joint. (See Fig. 2.) When the glue has set it is put through a double surfacer set at 13/16 in., which is the standard thickness used by most manufacturers. It is now ready to be laminated

2 The lumber goes to a glue jointer, where three types of joints may be used. (See Fig. 3.) After jointing it goes to the glue room for edge-gluing on rotary clamps.[2] Most of the manufacturers have found a 39-section clamp the most economical, both in first cost and operation. Steam pipes are usually placed on the floor under these clamps to speed up the drying, which gets the same result that a 59-section clamp would produce. After the glue has set the panels are S2S (surfaced two sides) to 13/16 in. and are ready to be laminated.

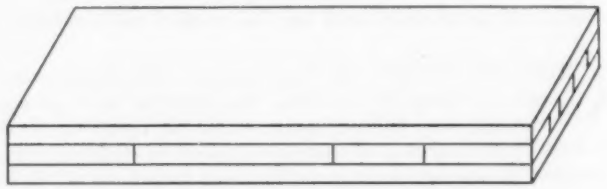


FIG. 4 USE OF SHORT NARROW PIECES IN CENTRAL PLIES



FIG. 5 REASON FOR AVOIDING SHORT-PIECE CONSTRUCTION IN BAND-SAWN AND SHAPED STOCK

In making up the panels another factor should be taken into consideration—that is, the use of narrow and short pieces of lumber. Previous to this time these have been considered waste. Most specifications today permit the use of narrow lumber (narrow lumber as used here means strips from 1 in. to 3 in. wide) in all panels, provided the narrow pieces are the full length of the finished panel. With low labor costs in the South it is possible to utilize this narrow lumber and show a substantial saving. In using narrow lumber it is better to make up the panels over a glue jointer and rotary clamp as the percentage of waste[3] is less than with a linderman machine, also labor is less.

Specifications issued by consumers now allow short-end glued lumber to be used, but only in the inside plies of panels having 3 or more plies (Fig. 4). The general reason given for not

[2] See "Design and Application of Clamp Carriers for Wood Gluing," by Raymond W. Burns of James L. Taylor Manufacturing Company, Poughkeepsie, N. Y., in *Mechanical Engineering*, May, 1926.

[3] See "Plywood Cores as a Foundation for Good Woodwork," by E. V. Knight and J. D. Perry, A.S.M.E. Transactions, WDI-51-13.

allowing this method of construction on outside of panels is that all shaper work is done on the outside plies and they do not think end-glued construction would give the desired results. There have been very few attempts to experiment along this line. In one experiment the shaper knives did throw a piece of end-glued stock from the piece, and this one failure seems to have determined the fate of end-glued stock on outside plies. However, the use of end-glued small pieces to make up panels for center plies has proved satisfactory both to manufacturers of wood parts and to consumers.

End-glued lumber in the body plant on parts such as side roof rails, rear belt rails, seat-back frames, and body hinge-pillar extensions have come into general use and have proved satisfactory both from a use and cost standpoint. A hydraulic press used for clamping up laminated lumber parts is shown in Fig. 6.

End-Jointing Lumber Parts

As an example take a side roof rail which has a sweep both horizontally and vertically. This is made from three pieces of

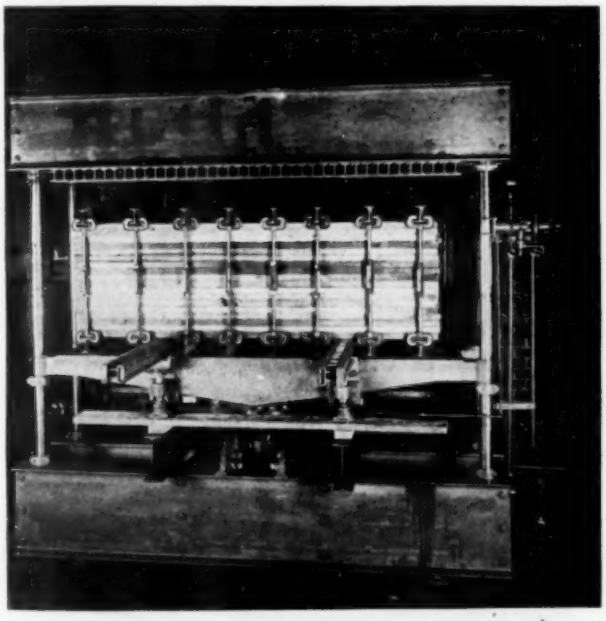


Fig. 6 Press and Method of Clamping Laminated-Lumber Parts

lumber end-glued to conform as near as possible to the final shape of the finished piece. This is done by using what is commonly known as a "finger joint." (Fig. 7.) This finger joint can be used to join two pieces of lumber at a vertical or horizontal angle, or a combination of both at the same time. A special machine and cutters are sold to do this work, and one can be found in nearly any body woodworking plant. This joint should be glued under pressure, furnished either by hand screw or compressed air. The compressed air is faster and gives a better quality of work. All joints should be clamped with a "C" clamp while under pressure, and should not be removed until the glue has set. Some mill men also used a dowel pin through the joint (Fig. 8) as an added factor of safety, but this is not generally practiced.

The preparation of these finger joints has been much facilitated by recent developments of several pneumatic-motored machines. These pneumatic-motored or air-turbined machines permit a much higher operating speed than has been practical with electric motors, and hence have permitted more efficient operation and smoother cutting. Several of the types of joints used in these machines, and also the cutter heads that are especially designed for such joints, are shown in Figs. 9, 10, and 11.

Finger jointing offers not only the opportunity of angling finger joints, as shown in Fig. 8, but also offers an opportunity of building up lengths from shorter pieces in order to obtain ultimate lumber strength in the final product. Tests have shown that while these finger joints may not produce full-strength lumber, yet their factor of strength is sufficient for most practical purposes. It is quite conceivable that four 6-in. pieces might be jointed together for a single 24-in. piece to be used in laminated work. Finger joints are already used in certain branches of other woodworking industries, such as the making of grand rims for pianos and the jointing of thin maple for piano backs.

Laminating Presses

The laminating should be done in a press, either hydraulic or electric, where a pressure of 100 lb. per sq. in. can be obtained over a large surface. (See Fig. 6.) The size generally used is 36 in. by 108 in. This size is most desirable because truck and bus-body sills are 8 ft. and longer. A motor-driven glue spreader is used and should be large enough to take 36 in. widths. Glue should be spread on both surfaces that are to be laminated. This is particularly desirable where oak is the wood to be laminated. On softer texture woods, such as gum, soft maple, and magnolia, glue spread on one surface might be sufficient, but on oak auto-

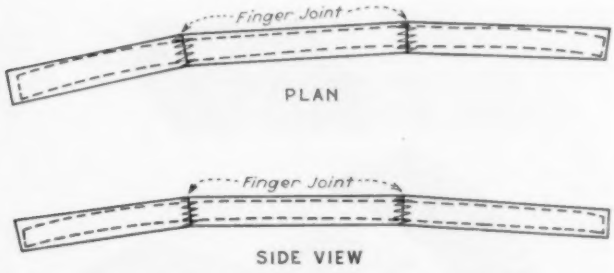


Fig. 7 Angles of End Jointing Required for Side Roof Rail

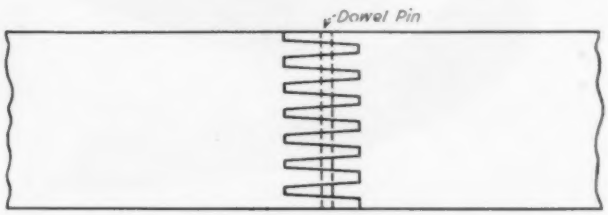


Fig. 8 Finger Joint With Wood or Metal Dowel

mobile body stock, where numerous operations are performed, including shaper cuts, the glue should be spread on both surfaces. Use of laminated stock in body work has proved that single spreading is not sufficient.

Glues Required

In laminating, both hot and cold glue are used. In using hot animal glue care should be exercised to regulate the temperature conditions in the glue room. The most satisfactory method developed up to this time is to have an annealing room adjoining the glue room. The temperature in this annealing room should be kept as near 100 deg. as possible at all times. The panels are on trucks or skids, and should have strips between them in order that the heat may penetrate the surface of the panels at all points. Panels should remain in the annealing room 48 hr. or longer. The glue room should be kept at a temperature between 80 and 90 deg. fahr. After the glue has been spread on the panel no air

draft or wind should be allowed to reach it; if it does it will cause a slight "skin" to form on the glue surface, and an inferior glue joint will be the result. While the panels are under pressure in the press the clamps are applied and pulled up tight. (Fig. 3.) The stock should remain in the clamps for at least 24 hr. In using cold glue it is recommended that a pressure slightly higher than 100 lb. per sq. in. should be used. Temperature conditions are not so important.

After the stock is taken from the clamp it should be taken to the rough mill and have the ends trimmed square, and in some cases the edge should also be squared in order that the straight edge can be used as a stop for making patterns. This is particularly true on sills and pillars.

Gluing Curved Surfaces

The work so far described has related wholly to flat gluing, but there is a vast field available for gluing curved shapes with thinner



Fig. 9 Types of Finger Joints Commonly Used

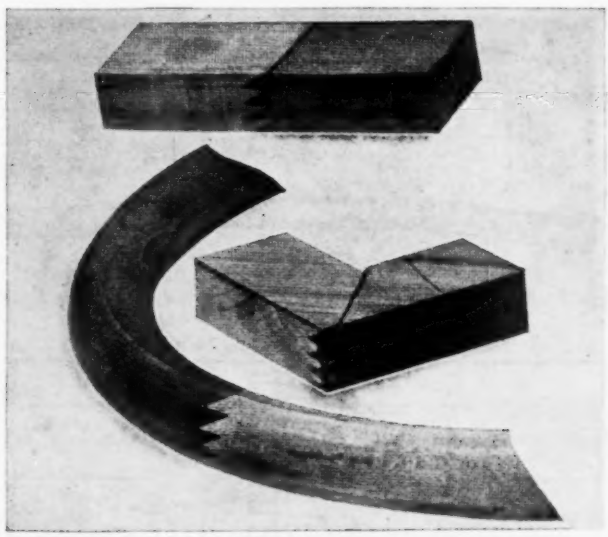


Fig. 10 Typical Straight, Miter, and Curved Joints

lumber so as to permit stronger and sturdier curved-piece construction. In fact, one body company is gluing up side roof rails to shape by using two or more pieces of 4/4 laminated to give the desired thickness. These roof rails are to exact curves, both horizontally and vertically, and several shaper operations are eliminated.

This involves the use of curved cauls in the glue presses, but will almost wholly eliminate the tendency of curved pieces to split and will largely increase the strength of the same over those that are band-sawn out of flat glued lumber.

This underlying policy also can be carried forward by the use of various kinds of rotary-cut veneer, which will permit an infinite variety of shapes and arrangements of parts with the minimum of weight and maximum of strength. Just how far economic conditions will justify the use of these curved forms is yet to be determined, but they offer a very interesting and intriguing field of research that should have early and complete investigation.

General Results

The use of laminated woods has done much to conserve the timber supply, because it permits the use of species of woods not previously used in body construction. It has done much to increase the use of lower grades of lumber and has brought about increase in woodworking plants in the South. Of course, the main object was cost reduction and this has been accomplished to an extent not thought of three years ago. Laminated woods have reduced the cost of medium-priced bodies by as much as $5 per body.

Appendix

GENERAL SPECIFICATIONS FOR DIMENSION STOCK

4/4 in.–8/4 in.–10/4 in.–12/4 in.

"A" *Clear Stock.* Free from defects of any description.

"B" *Sound Cuttings.* This grade permits sound tight knots as follows; Pieces 3 in. and wider knots up to 3/4 in. in diameter. Pieces 2 1/2 to 3 in. wide knots up to 1/2 in. diameter.

All other defects are excluded except small surface checks, stain, and similar defects that will dress out in surfacing as follows, 4/4 shall dress 1 7/16 in., 8/4 shall dress 1 15/16 in., 10/4 shall dress 2 7/16 in., 12/4 shall dress 2 15/16 in. Each piece may contain one defect per lineal foot, or the equivalent, provided the defects are not so situated as to decrease the strength of the piece.

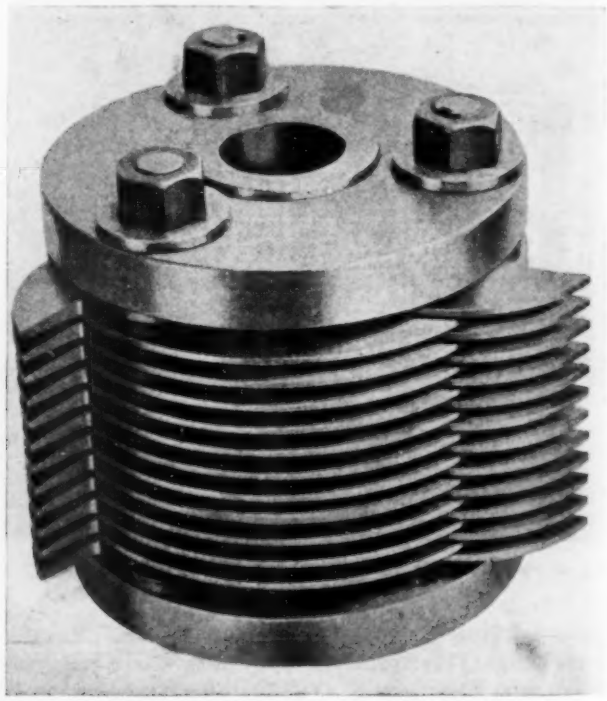


Fig. 11 A Patented Lock-Joint Grooving Head

"C" *Sill Stock Solid.* May contain sound tight knots up to 3/4 in. in diameter. Each piece may contain one defect per lineal foot, or the equivalent, provided the defects are not so situated as to decrease the strength of the piece. Stock must be free from warp or surface bend. If surfaced one side stock must be at least 1 7/8 in. thick. Scant stock will be rejected.

Linderman Sill Stock. Width of stock must be at least:

50 per cent—4 in. and wider
40 per cent—2 1/2 in. to 4 in. wide
not more than 10 per cent—2 in. to 2 1/2 in. wide.

Pieces 4 in. and wider may contain sound tight knots 3/4 in. in diameter.

Pieces 2 1/2 to 4 in. wide may contain sound tight knots up to 1/2 in. diameter.

Pieces 2½ in. wide must be clear.

Each piece may contain one defect per lineal foot, or the equivalent provided the defects are not so situated as to decrease the strength of the piece. Stock must be free from twist, warp, and all other defects that will not dress out in surfacing one side to standard thickness of 1 15/16 in. Thirty per cent of all sill stock under heading "C" must be Solid.

"D" *Sound Cutting* "B" except that knots must be at least 3 in. from ends.

"E" *Sound Cuttings* "B" except knots must be at least 6 in. from ends.

"F" *Sound Cuttings* "B" except knots must be at least 9 in. from ends.

GENERAL ITEMS

(1) Stock shall not contain more than 8 per cent or not less than 5 per cent moisture content at time of shipment.

(2) Species of lumber shown on cutting bill must be used.

(3) Dimensions shown on cutting bill have no minus allowance, the plus allowance is ¼ in. in width or thickness, a plus allowance of 1½ in. in length is permitted unless otherwise noted. Scant stock will be rejected.

(4) Stock to be bundled and marked with part number shown on cutting bill.

(5) Honeycomb is cause for rejection.

Airplane Spruce

By E. J. FISHBAUGH,[1] HOQUIAM, WASH.

The author seeks to prove that wood is a better material than metal in airplane construction where strength is required, airplane spruce being the material against which all other materials are checked for suitability. The paper indicates that airplane spruce gives the least possible weight with the greatest possible strength. There is a stand of Sitka spruce available for airplane manufacture, the author attempts to show by statistics, that will outlast the present generation of builders.

THIS paper might well be entitled Airplane Wood, as airplane spruce has become the standard against which all other wood, and in reality all other material in which strength is required, is judged as to its suitability for airplane construction. Thus far in the development of the aircraft industry, no material has been found superior to Sitka spruce in its ratio of strength to weight. As it is essential to have the least possible weight, and at the same time keep the greatest possible strength, Sitka spruce has become the chief material used for wing beams or spars in airplane construction.

The designers of the best-known planes and those making the great historical flights have understood this so well that their planes were designed to use spruce in their wing construction. In this connection uninformed men are often found who shake their heads in grave perplexity regarding the strength of spruce timbers of a given cross-section.

However, this very perplexity indicates two things. First of all is that they have not availed themselves of the accurately tabulated information to be had for the asking at the Forest Products Laboratory, Madison, Wisc. Here is to be found a fund of knowledge accumulated through years of painstaking laboratory experiments, by men thoroughly equipped, both technically and practically, to get results which are plain guides to the lumbermen and to the designing engineers.

The laboratory has made thousands of tests as to strength. It has ascertained that the average specific gravity, based on oven-dry weight and volume, of 0.40 will bear a reduction to 0.36 and still maintain its factor of strength and that an increase in specific gravity is an indication of added strength, although for purposes of airplane construction, keeping always in mind the desirability of lightness, the majority of lumber should keep somewhere within 10 per cent below and 10 per cent above the average of 0.40.

The second thing, indicated by perplexity in the mind of the designing engineer as to whether the strength factors can be accurately gaged in a timber, is that he is not familiar with the fact that men who have worked in timber and are experienced in this line of activity can tell by a surface examination of a piece of spruce whether it is what we call a live, strong piece or a brash, useless piece. Those who have studied the strength properties of spruce are able to read the indications put there by nature. Nature puts up its own signs, which have an unmistakable meaning to those who have learned the language.

Metal, being the result of chemical combination, cannot be judged thus accurately by any other than a laboratory test. Designers who have built planes around both materials are usually free to admit that the experience and data available concerning spruce and its properties leave in the mind of the designer less uncertainty as to the ultimate result than about any other material.

In this connection it is interesting to record a statement of one of the most prominent engineers connected with the aircraft industry, to the effect that in estimating the performance of newly designed ships it has been his experience that wood construction usually works out in actual practice at 5 to 10 per cent better than the original estimate and that metal usually has worked out in actual performance 5 to 10 per cent under the theoretical expectation.

The question is often asked, "How long before all the spruce will be used up?" And it is perhaps well to indicate here that there are three species of spruce which have been found to have equal value from the standpoint of the strength-weight ratio: Sitka spruce (*Picea sitchensis*), red spruce (*Picea rubra*), and white spruce (*Picea glauca*). Of the three species Sitka spruce has been found for all purposes to be by far the best, as it can be obtained in greater quantity and in more desirable sizes. The other species named are not capable of producing large timbers meeting Government specifications.

There is a stand of approximately 30 billion ft. of Sitka spruce timber available. Government statistics compiled show that there is approximately 2½ per cent of airplane lumber possible from spruce logs. At the present rate there is being produced about 300,000,000 ft. of Sitka spruce per year, which would give a yield of about 7,500,000 ft. of airplane spruce per year for the next 100 years. The present requirements of the airplane industry are about 2,500,000 ft. per year, based on last year's production. So it would seem that the present generation of designers and builders has little to worry about as to reliability of supply.

Another question frequently heard from purchasing agents and manufacturers is, "Do we have to use spruce—isn't there some other wood we can use?" They do not have to use spruce. There are two other woods which show approximately the same strength-weight ratio; viz., Port Orford cedar and old-growth yellow Douglas fir. (See Table 1, "Strength Values of Various Woods. . . for Use in Aircraft Design," which was prepared by the Forest Products Laboratory and has been adopted as standard by the Army Air Service, Bureau of Aeronautics, Navy Department, and the Department of Commerce.) The first of these looks very much like Sitka spruce, although it is slightly heavier and is found in only a very small area and, thinking in terms of an industry, in insufficient quantities to warrant making designs which would depend upon it for a supply. Old-growth yellow Douglas fir is a splendid wood and is found in large volume all along the Northwestern coast. It is considerably heavier than Sitka spruce, and if used would require special designs by reason of its greater weight. In case of a national emergency,

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[1] Posey Mfg. Co. Mr. Fishbaugh received his education at the State Normal School, Brockport, N. Y. During 1916–19 he was superintendent of Hobart M. Cable Company, LaPorte, Ind.; in 1919–22 vice-president in charge of manufacturing for A. B. Chase Piano Company, Norwalk, Ohio; in 1922–26 factory manager for Lyon & Healy, Chicago, Ill.; from 1926 sales engineer for Posey Manufacturing Company, Hoquiam, Wash. Mr. Fishbaugh claims that it was his good fortune early in life to become acquainted with men who helped him to think of production in terms of the engineer.

Contributed by the Wood Industries Division and presented at the Semi-Annual Meeting, Detroit, Mich., June 9 to 12, 1930, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

TABLE 1 STRENGTH VALUES OF VARIOUS WOODS, BASED ON 15 PER CENT MOISTURE CONTENT, FOR USE IN AIRCRAFT DESIGN

Species of wood; common and botanical names	Specific gravity based on volume and weight when oven-dry Average	Min. permitted	Weight at 15 per cent moisture content lb. per cu. ft.	Shrinkage from green to oven-dry condition based on dimensions when green Radial per cent	Tangential per cent	Static bending: Fiber stress at elastic limit[1] lb. per sq. in.	Modulus of rupture[1] lb. per sq. in.	Modulus of elasticity[2] 1000 lb. per sq. in.	Work to max. load, in-lb. per cu. in.	Compression parallel to grain: Fiber stress at elastic limit[1,3] lb. per sq. in.	Maximum crushing strength[1] lb. per sq. in.	Compression perpendicular to grain[4] lb. per sq. in.	Shearing strength parallel to grain[5] lb. per sq. in.	Hardness side; load, required, to imbed 0.444-in. ball to one-half its diameter, lb.
Hardwoods (broad-leaved species):														
Ash, black (Fraxinus nigra)	0.53	.48	35	5.0	7.8	6400	11900	1340	14.3	4050	5400	1260	1050	760
Ash, commercial white (Fraxinus spp.)[6]	0.62	0.56	41	4.3	6.9	8900	14800	1460	14.2	5250	7000	2250	1380	1180
Basswood (Tilia glabra)	0.40	0.36	26	6.6	9.3	5600	8600	1250	6.6	3370	4500	620	720	370
Beech (Fagus grandifolia)	0.66	0.60	44	4.8	10.6	8200	14200	1440	13.5	4880	6500	1670	1300	1060
Birch (Betula spp.)[7]	0.68	0.58	44	7.0	8.5	9500	15500	1780	18.2	5480	7300	1590	1300	1100
Cherry, black (Prunus serotina)	0.53	0.48	36	3.7	7.1	8500	12500	1330	11.7	5100	6800	1170	1180	900
Cottonwood (Populus deltoides)	0.43	0.39	29	3.9	9.2	5600	8600	1190	7.4	3520	4700	650	660	410
Elm, rock (Ulmus racemosa)	0.66	0.60	45	4.8	8.1	7900	15000	1340	19.3	5180	6900	2090	1360	1230
Gum, red (Liquidambar styraciflua)	0.53	0.48	34	5.2	9.9	7500	11600	1290	10.9	4050	5400	1190	1100	650
Hickory (true hickories) (Hicoria spp.)[8]	0.79	0.71	51	...	...	10600	19300	1860	27.5	6520	8700	3100	1440	....
Mahogany, African (Khaya spp.)	0.47	0.42	32	4.8	5.5	7900	10800	1280	8.0	4280	5700	1400	980	720
Mahogany, true (Swietenia spp.)[9]	0.51	0.46	34	3.4	4.7	8800	11600	1260	7.3	4880	6500	1760	860	790
Maple, sugar (Acer saccharum)	0.67	0.60	44	4.8	9.2	9500	15000	1600	13.7	5620	7500	2170	1520	1270
Oak, commercial white and red[10] (Quercus spp.)	0.69	0.62	45	4.6	9.0	7800	13800	1490	13.6	4950	6600	1870	1300	1240
Poplar, yellow (Liriodendron tulipifera)	0.43	0.38	28	4.0	7.1	6000	9100	1300	6.5	3750	6000	810	800	420
Walnut, black (Juglans nigra)	0.56	0.52	39	5.2	7.1	10200	15100	1490	11.4	5700	7600	1730	1000	990
Softwoods (conifers):														
Cedar, incense (Libocedrus decurrens)	0.36	0.32	25	3.3	5.7	6000	8700	1020	5.6	4320	5400	900	650	450
Cedar, Port Orford (Chamaecyparis lawsoniana)	0.44	0.40	30	4.6	6.9	7400	11000	1520	8.7	4880	6100	1030	760	520
Cedar, western red (Thuja plicata)	0.34	0.31	23	2.5	5.1	5100	7800	1030	5.8	4000	5000	800	630	320
Cedar, northern white Thuja occidentalis)	0.32	0.29	22	2.1	4.9	4700	6600	700	4.9	3040	3800	560	610	300
Cypress, southern (Taxodium distichum)	0.48	0.43	32	3.9	6.1	7100	10500	1270	7.7	4960	6200	1230	720	480
Douglas fir (Pseudotsuga taxifolia)	0.51	0.45	34	5.0	7.8	8000	11500	1700	8.1	5600	7000	1300	810	620
Pine, Norway (Pinus resinosa)	0.51	0.46	34	4.6	7.2	8500	11900	1560	8.9	5280	6600	1080	870	520
Pine, sugar (Pinus lambertiana)	0.38	0.34	26	2.9	5.6	5600	8000	1040	5.4	3680	4600	810	730	370
Pine, western white (Pinus monticola)	0.42	0.38	27	4.1	7.4	6000	9300	1310	7.9	4240	5300	750	640	360
Pine, northern white (Pinus strobus)	0.38	0.34	26	2.2	6.0	5900	8700	1140	6.3	3840	4800	780	640	380
Spruce (Picea spp.)[11]	0.40	0.36	27	4.1	7.4	6200	9400	1300	7.8	4000	5000	840	750	440

[1] The average values for fiber stress at elastic limit and modulus of rupture in static bending and fiber stress at elastic limit and maximum crushing strength in compression parallel to grain have been multiplied by two factors to obtain values for use in design. A statement of these factors and of the reasons for their use follows: It was thought best, in fixing upon strength values for use in design, to allow for the variability of wood and the fact that a greater number of values are below the average than above it, and the most probable value (as represented by the mode of the frequency curve) was accordingly decided upon as the basis for design figures. From a study of the ratios of most probable to average values for three species (Sitka spruce, Douglas fir, and white ash), 0.94 was adopted as the best value of this ratio for general application to the properties in question. The stress that wooden members can carry depend on its duration. A factor of 1.17 has been applied to test results to get values of the stress that can be sustained for a period of 3 seconds, it being assumed that the maximum load will not be maintained for a longer period.

[2] The values given are the most probable values (92 per cent of the average) of the apparent modulus of elasticity (E_c) as obtained by substituting results from tests of 2 by 2 in. beams on a 28-in. span with load at the center in the formula $E_c = P13/48\Delta I$. The use of these values of E_c in the usual formulas will give the deflection of beams of ordinary length with but small error. For exactness in the computation of deflections of I and box beams, particularly for short spans, the formula that takes into account shear deformations (see National Advisory Committee for Aeronautics Report No. 180, "Deflection of Beams With Special Reference to Shear Deformations") should be used. This formula involves E_T, the true modulus of elasticity in bending, and F, the modulus of rigidity in shear. Values of E_T may be obtained by adding 10 per cent to the values of E_C as given in the table. If the I or box beam has the grain of the web parallel to the axis of the beam, or parallel and perpendicular thereto, as in some plywood webs, the value of F may be taken as $E_T/16$ or $E_c/14.5$. If the web is of plywood with the grain at 45 deg. to the axis of the beam F may be taken as $E_T/5$ or $E_c/4.5$.

[3] Design values for fiber stress at elastic limit in compression parallel to grain were obtained by multiplying the values of maximum crushing strength as given in the next column by factors as follows: 0.75 for hardwoods, 0.80 for conifers. Values as given are to the nearest 10 lb.

[4] Wood does not exhibit a definite ultimate strength in compression perpendicular to grain, particularly when the load is applied over only a part of the surface, as it is at fittings. Beyond the elastic limit the load continues to increase slowly until the deformation and crushing become so severe as to seriously damage the wood in other properties. Figures in this column were obtained by applying a duration of stress factor of 1.17 (see Note 1) to the average elastic limit stress and then adding 33⅓ per cent to get design values comparable to those for bending, compression parallel to grain, and shear as listed in the table.

[5] Values in this column are for use in computing resistance of beams to longitudinal shear. They are obtained by multiplying average values by 0.75. This factor is used because of the variability in strength and in order that failure by shear may be less probable than failure from other causes. Furthermore, tests have shown that because of the favorable influence upon the distribution of stresses resulting from limiting shearing deformations the maximum strength-weight ratio and minimum variability in strength are attained when I and box beams are so proportioned that the ultimate shearing strength is not developed and failure by shear does not occur.

[6] Includes white ash (F. americana), green ash (F. pennsylvanica lanceolata), and blue ash (F. quadrangulata).

[7] Includes sweet birch (B. lenta) and yellow birch (B. lutea).

[8] Includes bigleaf shagbark hickory (H. laciniosa), mockernut hickory (H. alba), pignut hickory (H. glabra), and shagbark hickory (H. ovata).

[9] Includes material from Central America and Cuba.

[10] Includes white oak (Q. alba), bur oak (Q. macrocarpa), swamp chestnut oak (Q. prinus), post oak (Q. stellata), red oak (Q. borealis), southern red oak (Q. rubra), laurel oak (Q. laurifolia), water oak (Q. nigra), swamp red oak (Q. pagodafolia), willow oak (Q. phellos), yellow oak (Q. velutina).

[11] Includes red spruce (P. rubra), white spruce (P. glauca), and Sitka spruce (P. sitchensis).

this wood offers an unlimited supply to supplement the already large supply of Sitka spruce available. The chief obstacle to the use of this wood for aircraft, outside of the extra weight-strength ratio, is the fact that up to the present time this species has been manufactured largely upon a commercial volume basis rather than on a quality selection basis.

The production of wood for airplanes necessitates a high-grade remanufacturing plant with a personnel thoroughly experienced in selecting lumber for its strength qualities. Again, thinking in terms of economics, for the last 20 years engineering experts have been building up tables of experience, based upon the use of Sitka spruce, and at least one high-grade remanufacturing specialist, the Posey Manufacturing Company, Hoquiam, Wash., has been accumulating and supplying material for the airplane industry based upon practical as well as technical knowledge and experience. In view of this information and the unlimited supply, for practical purposes, of Sitka spruce (about which there is probably more known than about any other available material) it would not seem economically sound to venture into new fields for material.

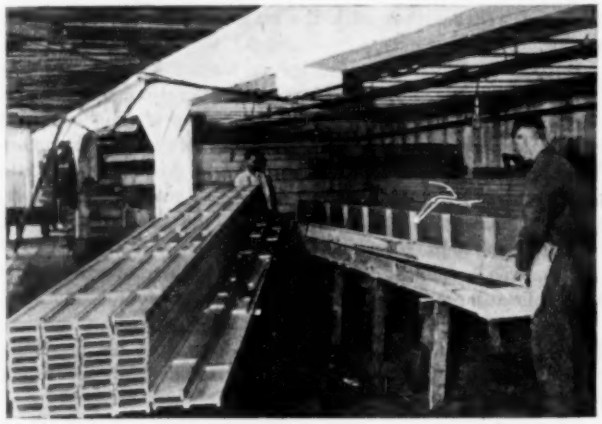


FIG. 1 PACKING SITKA SPRUCE AIRPLANE SPARS
(These are fully worked to blueprint dimension and are being shipped to the airplane manufacturer.)

The availability of dimension, laminated, and spliced spars, should not be overlooked in planning the production program for a new shop layout, and as a matter of fact it is well to consider the use of dimension stock in any of the present airplane factories using spruce parts because a thorough study of this matter will show that a dimension program is economically sound and fundamentally correct.

The automobile body manufacturers, refrigerator and piano manufacturers, and others have found that a tremendous saving is made by purchasing their wood requirements cut to net sizes and manufactured more or less ready for assembly. This eliminates a heavy investment for machines and the floor space necessary for manufacture, besides greatly reducing the amount of capital required, as well as taxes and insurance; the result is no sacrifice in quality and permits a greater potential machine production capacity. Furthermore, there is not only a saving of time in cost accounting, but more accurate costs are obtainable, because the problem of the cost of waste is virtually eliminated so far as the airplane manufacturer is concerned.

Many people make comparisons between the automobile and airplane industries, and in the mind of the public generally there seems to be the thought that airplanes will soon be as numerous as automobiles. Practically, this is not true, and there is no evidence at present that it ever will be true. Previous to the historic flight made by Colonel Lindbergh, very few planes were made except for use by the Army and Navy. Beginning immediately after that great flight, individual engineers, aviators, and the general public became wildly enthused over the possibilities in airplane manufacture and travel. The production ratio for the years following has been about in the proportion of 2 for the first year, 4 for the second, 8 for the third, and 12 for the last year. Up until last year, any plane built could be sold as soon as finished, and many were sold before they were started. But the airplane industry awoke suddenly last October to find that it needed to study its market, as already it had built enough planes to last well through the first quarter of 1930.

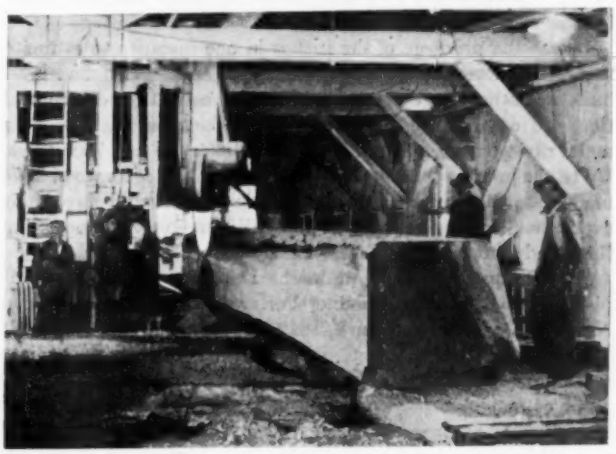


FIG. 2 SAWING A SITKA SPRUCE AIRPLANE LOG
(Squaring up of a No. 1 log, ready to saw off cants to make airplane lumber. It is the part nearest the bark from which airplane and other strength timber is procured.)



FIG. 3 "POSEY INSPECTED AERO" GRADE OF LUMBER
(Timber from a No. 1 log being examined to remanufacture, first being marked to save the airplane lumber in it.)

The fear in the minds of manufacturers and engineers as to the available supply of spruce, together with the vision of high production and the very splendid sales approach by the advocates of wood substitutes, has led to some use and considerable experimentation with metal.

Rapid progress in the airplane industry has made what seemed to be good usage in the first half of the year entirely out of date by the end of the year. In many instances, with engineering pans approved and ordered into production, they have been

changed, sometimes radically, before the first production planes were completed. Even in some of the largest production units of the country probably there is not over a half dozen who have made as high as a thousand planes of one type, and very few have made over a hundred of one type, without a radical change of some kind. Because of the small number made by any company of one type of plane and the great expense involved for dies for metal construction, for practical purposes wood unquestionably is the superior material and will maintain its position even though metal should be perfected to the point where it would become of equal value technically.

It was the privilege of the author in one instance to estimate the cost of wood ribs for a certain type ship which had been built in rather large quantity. The investigation determined that the cost of the equipment with which to begin making metal ribs would pay for all the wood ribs for the first 750 planes. Up to the present time, while makers of substitutes for wood have made great progress in perfecting their product and have done exceptional promotion work, wood still remains enthroned from the standpoint of utility and economy.

A paper entitled, "Factors in the Design of Commercial Airplanes," read by Charles Talbot Porter at the annual meeting in New York City, December 2, 1929, of The American Society of Mechanical Engineers, contained an interesting paragraph in this connection. In reviewing existing airplanes from the standpoint of materials used, it was stated that a great variation of thought was at once apparent. There had been much talk, it was said, of the fundamental advantage over wood of the all-metal rowboats, all-metal houses, etc., but the airplane engineer was urged to select his materials for each case with the best combination of safety, durability, cost, and performance; and while, for reasons of safety and cost, to some extent wood had been abandoned for body construction, the case of wood for wing-beam construction was still very strong.

In connection with the foregoing, it might be pointed out that one of the largest producers of automobiles in the world has recently carried out exhaustive tests looking toward safety, durability, cost, and performance in automobile bodies, and after the most painstaking tests he has decided to abandon largely the metal construction and revert to wood.

As to the fire risk, of course the recent deplorable accidents in the transport field with all-metal ships, which were consumed by fire, does away with any argument regarding the greater risk of wood construction. This is strikingly demonstrated also in automobiles, where the fire risk with wood-constructed bodies is considered no greater than with all-metal.

Referring again to Government statistics which indicate that about 2½ per cent of the total cut of spruce is all that has the requisite quality for use in airplane construction, it will be seen that there is a serious matter of inspection and selection necessary before a given piece can be placed in the wing of a finished plane. In this connection it is well to consider some of the specifications laid down by the Government relative to quality of airplane lumber, as follows:

Material:

1 The lumber shall be sound and clear on four sides, and free from all decay. Bright sap, knots, or equivalent burls ¼ in. or less in diameter, and narrow pitch pockets and bark seams 1½ in. in length, shall not be considered defects.

2 The grain shall be straight, that is, the angle of deviation from a line parallel to the edges shall not exceed 1 in. in 15 in. Vertical or flat grain will be accepted.

3 The rate of growth of any piece shall be not less than six annual rings to each inch when measured in a radial direction on either end section through the zone of maximum growth.

These are some of the specifications, but in actual practice their proper interpretation is the important thing, as here it is that experience counts.

It is to be said in behalf of the Department of Commerce in charge of commercial aeronautics that it is a group of young men, technically trained, industriously working with high ideals to accomplish the greatest possible good for the airplane industry and the public. When one says "airplane lumber" he should have in mind lumber that not only answers the foregoing specifications but lumber that has strength as its first characteristic.

The accompanying photographs show different operations in the production of airplane spruce.

Discussion

R. L. Hankinson.[2] The author has presented the subject largely from the standpoint of the lumber manufacturer who furnishes the airplane builder with spruce, either as a raw material or in a semi-manufactured form, such as wing beams, wing ribs, etc. From study of the use of spruce in airplane construction, the writer agrees with the statements presented by the author.

During the World War the spruce needed for airplanes was furnished by the Spruce Production Corporation, which functioned under Government supervision. For a time following the armistice some of the airplane spruce left over from manufacturing Government planes was sold and found its way into the manufacture of commercial planes. About 1922, however, airplane builders began to complain of the scarcity of spruce for airplane manufacture and to look for substitutes. The opinion was broadcast among the airplane manufacturers and the public at large that some substitute must be found for spruce.

Three causes were responsible for the prevailing opinion: First, the airplane manufacturer, not foreseeing his needs far enough in advance, attempted to obtain airplane spruce for quick delivery, the same as he would buy nails, bolts, etc., forgetting that it was not a commercial commodity. In the second place, a few lumber dealers attempted to supply commercial spruce in place of the higher-grade material needed for airplanes which was unsatisfactory to the airplane manufacturer. The third reason was that the market for airplane spruce was a negligible quantity and no manufacturer of spruce lumber could afford to gradually accumulate the very best of the run of his production to supply a very doubtful market where there were no size standards existing.

The paper points out that the existing stand of spruce is adequate to meet the needs of airplane manufacturers for years to come, even though no consideration is given to the yearly growth of spruce. Especially is this statement true if airplane manufacturers can be educated to the use of built-up beams and other spruce members which will allow the utilization of the pieces of smaller cross-section and shorter lengths which are of airplane grade. It may be stated that there is a scarcity of airplane spruce for wing beams of large cross-section and long lengths because nature grows but few trees which will produce such stock. An airplane manufacturer should in no way hesitate to use a wing beam or other highly stressed part which has been manufactured from several smaller pieces of spruce, using casein glue as an adhesive.

The writer was one of the very early advocates of this method of wing-beam construction, and after many experiments and tests made at the Matériel Division of the Army Corps at Dayton, Ohio, did everything possible to encourage manufacturers to adopt this type of construction, which construction was sanc-

[2] Wood Technologist and Research Engineer, U. S. Army Air Service, 1918 to 1929; present position Chief Engineer, Crescent Panel Company, Louisville, Ky.

t'oned for use on Air Corps contracts as early as 1921. It was the writer's privilege to follow the history of such construction until about one year ago, and he does not know of a structural failure which could be attributed to built-up spruce members.

There are a number of good designs for built-up wing beams which have been successfully used. One of the types most largely used is the so-called box-type beam, which consists of two spruce flanges and spruce planking for the beam sides.

The spruce flanges either can be laminated or made from a single piece in cross-section. Either type of flange may be spliced by means of a plane-scarfed splice to form the beams of the required lengths. The side members which resist the shear forces should be two-ply 45-deg. planking of either spruce or mahogany. Spruce planking for this purpose appears to be the favorite on account of its higher weight-strength ratio.

The writer would urge airplane manufacturers to place more reliance in reputable spruce and plywood manufacturers who stand ready to help the airplane manufacturer obtain the most suitable material for airplane construction. By such mutual cooperation some of the problems relating to the scarcity of spruce and unsatisfactory plywood will be satisfactorily settled to the mutual advantage of all parties concerned.

WDI-52-7

Manufacturing Upright- and Grand-Piano Cases

By JOSEPH T. LINDSEY,[1] ROCHESTER, N. Y.

In this paper the author tells of the various manufacturing operations that are necessary to complete piano cases, and describes the system of following work used by the Foster-Armstrong Company. Emphasis is placed on the fact that an efficient planing system is most essential to obtain best results. Operations carried out in the various departments together with the special machine tools used are described.

AN EFFICIENT drafting and planning system is one of the essential factors for obtaining best results in manufacturing piano cases. In the factory with which the author is connected a schedule sheet for every part is prepared. On this is given the part number, the kind of wood, the number of pieces, finished dimensions, cost-part numbers, operation numbers, and remarks telling what to do. Numbers are assigned for every operation from that of the swing-saw in the mill to the final operation at completion. As an illustration of the part-number system numbers from 1 to 100 are allotted to upright-piano cases and those from 101 to 200 to grand-piano cases. Practically every part number has a name. Drawings are made first, and are approved by the proper authorities, then the schedule sheet is made. When the schedule of operations is completed the sheet is filed in the case-shop office.

When a particular style appears on the layout, it is handled either by sheets or by tags. When a long run on a particular style is expected sheets are multigraphed. Blank spaces are provided for the lot number, kind of wood, veneer or stock to be used, etc. The tag system is used for slow-moving styles where it does not pay to put them on sheets. Layout check lists are distributed to all departments. The mill department received tags at this time. The foreman sorts the tags and checks them off on his check list as they are given out to the different swing-saws. When parts are completed they are checked out of the mill and into the department that receives them. This system continues until the work is completed.

Approximately 1,250,000 ft. of lumber is kept in the storage yard. This consists of 10 different kinds of wood varying in thickness from $^1/_8$ to $2^1/_2$ in. To keep a sufficient quantity of all kinds and dimensions, and to take care of a fluctuating layout, a schedule called the "minimum quantity" for the lumber yard is used. That quantity is based on an estimated amount so that no lumber will need to be delivered to kilns that has not been air dried for at least nine months.

The purchasing department receives a report the first and fifteenth of every month showing shortages. By following this scheme there is no excuse for not having ample air-dried lumber at all times regardless of the layout.

The mill foreman has charge of the kilns. He in turn gives the yard foreman orders as to the kind of lumber and amount needed. This is governed somewhat by the particular styles going through. The company with which the author is connected uses a box-type kiln with a conditioning shed between the kiln and the millroom. This layout is about the best for real results. It is the practice to keep all lumber in the conditioning shed for at least five days before cutting. That is ample time for cooling off and for taking on moisture necessary for a balanced condition equal to the average amount throughout the case shop.



FIG. 1 A HOME-MADE VENEER JOINTER

The tag system starts at the swing-saw. Each part has a tag to work by. With this system the department has a check list. This list calls for all parts that are used on this particular style. As a rule no two styles would ever have the same number of tags; therefore, check lists are different on every style. The list shows what has been delivered and what needs attention. It is a very simple scheme but very important.

The mill delivers to four departments. They are the veneer laying, back frame, machine assembling, and cleaning departments. The machine tools include a swing-saw, band-resaw, jointers, automatic jointer, planers, linderman, glue jointer, sticker, cylinder sander, dowel machine, tenoner, and continuous glue clamps.

VENEER CUTTING DEPARTMENT

Veneers are cut by schedule with part numbers as already mentioned. In the space for remarks are entered the number of pieces, single veneer on one side or two sides, double veneer on one side, etc. Otherwise, it is understood that it is to be double veneered on both sides. When special veneers are to be used that information also appears on the schedule. In fact, the schedule takes care of all details.

It is very important that veneers should be dried properly

[1] General Superintendent, Case Shop, Foster-Armstrong Co. Mem. A.S.M.E. Mr. Lindsey started work in a builder's finishing factory at the age of 16, remained in that line of work for 5 years and changed to mechanical pattern making for $10^1/_2$ years. He spent 2 years in designing and pattern making in piano-case work.

Presented at the Rochester Meeting, Rochester, N. Y., May 13 to 15, 1929, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

before cutting and taping. Lack of proper drying causes warping, twisting, checking, and open joints. When veneers are prepared properly, as a rule the percentage of replacement parts is very small. Cross-banding should never be dried any more after it has been taken care of by the manufacturer. Material is not used from a car that has just been unloaded. It is uncrated, piled, and in about two or three weeks' time, the moisture content is the same as that being used, or 8 to 10 per cent.

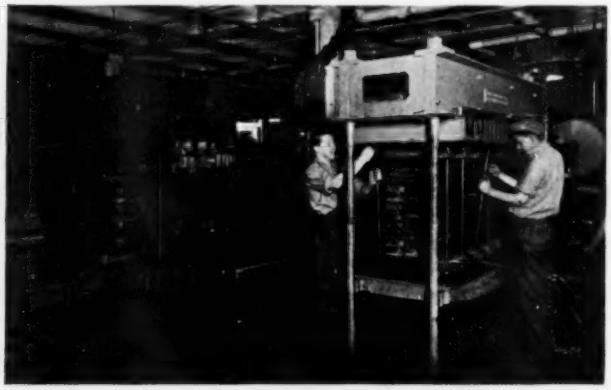


FIG. 2 HYDRAULIC PRESS IN THE VENEER LAYING DEPARTMENT

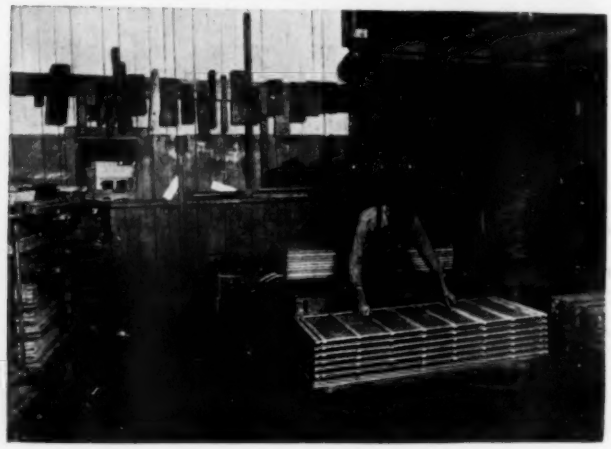


FIG. 3 OPERATION OF UNLOADING AND RACKING



FIG. 4 HAND-BLOCK BELT SANDER

Fig. 1 shows a veneer jointer. This is a home-made machine consisting of a bench, portable bench top, and an electric saw. A strip of steel is screwed to the entire length of the portable bench top to serve as a guide. A recess is cut in the electric saw frame that fits the strip that is on the portable bench top. Veneers are placed on the bench so as to work from the front edger. The portable table is placed on top of the veneers, and is held in place by guides at both ends of the bench and the portable bench top. The operator places the electric saw on the portable table, turns on the switch, and then pushes the saw the full length of the veneer. The current is then turned off and the saw is drawn back to the shelf. The portable bench top is then removed and is placed on its hangers. The veneers are then turned over as per the dimension required and then the procedure is repeated. This jointer is unlimited as to its capacity and can be used to advantage particularly in small shops that use veneers.

VENEER LAYING DEPARTMENT

Core-stock veneers and cross-banding are checked in and out as to lot number and part number by a check list. Three kinds of glue are used, vegetable, hide, and monite. Vegetable glue is used on at least 98 per cent of the flat work; on the remaining 2 per cent hide glue is used.

Hide glue is used on practically all circle work; that is, falls, moldings, etc. Monite is used on some parts when the layout is too great for the caul capacity as where two layings per day are obtained in the hydraulic press; that is, parts that pass through the sticker or molder.

Templets are made for the sticker. Cauls are made from the templet by a first-class trained mechanical pattern maker. By employing such a mechanic there are no loose veneers. In fact, all patterns, cauls, forms, jigs, and such tools are built by the pattern maker.

Great care is taken when unloading the presses and racking stock. About 85 per cent passes through the kiln. It is not necessary to put the thick stock through as moisture is absorbed in a very short time.

Fig. 2 shows a hydraulic press in the veneer-laying department. A batch of back falls is being clamped in retainers. All circle work is handled in this manner as it eliminates hand press work. At the left of the hydraulic press there is a truck with a batch of back falls of a different shape. The real success of handling circle work in the hydraulic press is through the use of the templet and by maintaining accuracy.

Fig. 3 shows the unloading and racking operation. Care in this is necessary to obtain good straight stock. Several sizes of racks are used so the combination is generally great enough to take care of the varied sizes. All veneered parts pass through this operation. Veneer dry-kiln stock remains in the kiln about 14 hr.

GRAND PIANO RIM DEPARTMENT

This department works by layouts, style, and lot number. Monite glue is used. Rims and skeletons are laid starting at 7:30 a.m. They are taken out of the presses at about 2 p.m. the same day. The second laying starts at that time. Rims that come from the press are taken to a bandsaw, the ends are cut off plus final length and then the bottom edge is jointed.

Retainers are placed on the treble and base sides. The next day they are put in the kiln for 48 hr. Final jointing of the bottom edge then takes place, cheeks are glued on, band-sawed to shape, and sawed to width. From this operation they are piled in the conditioning room for four to five weeks. Then they are taken to the machine department, cheeks are shaped, and other machine operations take place at this time. When com-

pleted they are delivered to the assembling and cleaning department, where they are completed, ready for inspection.

Machine Department

This department receives stock from the mill, veneer laying, and grand-rim laying departments. All work is carried through by tags and by the check-list system. This department is called the "Second Mill." The term "machine" is used because all parts are completed ready for assembling. The machine used in this department are: Jointers, saw benches, shapers, band- and jig-saws, boring machines, cylinder sander, stroke sanders, automatic lathe, hand lathe, carving machine, and edge veneering machine. Special equipment such as patterns, forms, cauls, etc., are furnished by the pattern makers. All completed parts are delivered to the assembling and cleaning department.



Fig. 5 Grand Skeleton Leveling Machine

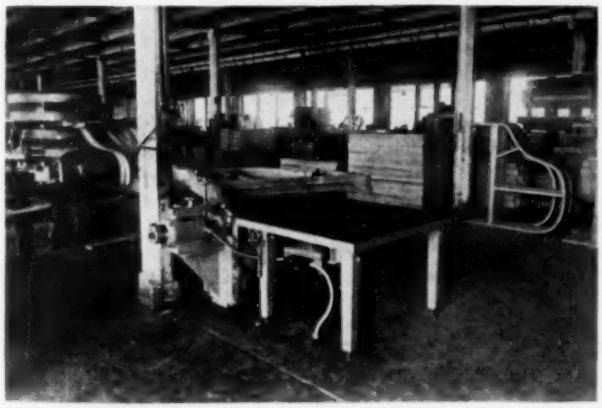


Fig. 6 Skeleton After Leveling Operation Has Been Completed

Cleaning Department

Practically all parts are delivered to this department by the machine department. Very few parts are delivered by the mill department. All work is carried through with the tag and check-list system. The tags furnish complete information as to operation. Drawings are not found necessary except possibly for the first lot going through. By eliminating the drawings production is somewhat larger than it was before the tag system was used. All the assembling or cabinet work is completed in this department.

It is necessary to return some parts to the machine department before they are machine sanded or hand sanded. All edge sanding, circle falls, moldings, and small parts are machine sanded in this department. The machines used are the edge belt, spindle, disk, and hand block. All work such as vein lining, fluting, small depressions, and cutting in leg plates are handled by small routers. They are very efficient.

Fig. 4 shows a hand-block belt sander. This machine has some special equipment. There is a vertical table and a pit is built in the floor. In this pit there is a platform that can be raised or lowered by the hand wheel shown at the left end just above the floor in the illustration. Parts up to 68 in. square are handled.

When sanding a square back-end, grand-piano rim or case, the rim rests on two arms which hook on to the top edge of the vertical table. They are long enough so the operator is able



Fig. 7 Crowning the Skeleton for the Sounding Board

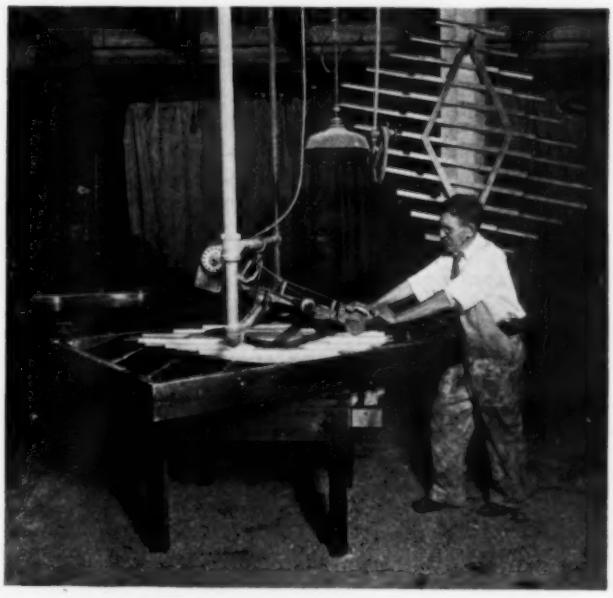


Fig. 8 Sounding-Board Scooping Machine

to slide the rim backward and forward. This enables him to sand the full width of the treble base and back end. The circle part is sanded by hand.

Fig. 5 shows a grand-piano skeleton-leveling machine. At the right is a form to assemble grand-piano skeleton parts. When completed in this form they are placed on a three-point bearing form on the leveling machine. In Fig. 5 the operator is passing a skeleton over the cutters. About $^1/_8$ in. is allowed on the bottom edge for leveling. As a rule this is sufficient. If not, the operator can raise the head enough to clean whatever is necessary.

Fig. 6 shows the skeleton completed as far as leveling is concerned. It is cleaned by the cabinet maker and in the machine department it is shaped on a form to exact shape and size.

The next operation shown in Fig. 7 is the operation of crowning the skeleton for the sounding board. This operation is very important. In order to eliminate the human element the electric planer is arranged so that the operator takes two cuts. About $^3/_{32}$ in. is left for the last cut. When completed by this operator, they are inspected and then delivered to the belly department where the sounding board is glued on, plate fitted, and the bearing taken. From this point they are delivered to the stringing department.

Fig. 8 shows the sounding-board scooping machine. This is a home-made machine of four parts. The base is a revolving frame. Over this is a swinging pipe frame. On this frame a machine on wheels rotates back and forth so as to cover the entire size of the sounding board. The sounding board is placed on a revolving frame, rib side up. Then the form is placed on the rib side of the sounding board. One of these can be seen hanging just back of the operator on a post. The operator can start on either end. When he has finished one side, he swings the frame that is on top of the base one-half around and then proceeds as before. This scheme eliminates any chance of error, and in turn insures a first-class job. All finished parts are inspected, checked, and delivered to the staining and filling department.

WDI-52-8

Mass Production of Radio Cabinets

By ARCHER W. RICHARDS,[1] CHICAGO, ILL.

The great demand for radio cabinets made it necessary for manufacturers to arrange their methods and machinery on a highly productive basis. The author in this paper tells of the production methods and machinery used by the Grigsby-Grunow Company. Lumber is purchased already dried and cut to exact dimensions for standard designs of cabinets. The material is received in matched sets, so parts are started through the mill immediately upon receipt and much storage space is saved and several handlings are eliminated. More rigid inspection is necessary with this method than with others so specifications for material were given careful attention. The paper describes the plant equipment, inspection methods, plant layout, and handling methods.

RADIO cabinets, in the beginning, were merely boxes to house the various component parts of the radio receivers, speakers, etc., and it is only within the past few years that the radio industry conceived the idea of a complete piece of furniture to house all of the mechanism of the radio receiver. The tremendous demand created for these compact, artistic outfits, as well as the low-selling price, called for deep study and intensive experimenting in the manufacture of well-made low-priced cabinets.

The furniture industry is one of the oldest in existence, and while low-priced furniture has been made, the lesson learned in mass production of other products did not seem to be accepted by the industry. Hence the Grigsby-Grunow Company found it necessary to build a complete cabinet plant which would combine the most modern production methods and machinery.

Rather strangely the development was made, not by experienced woodworkers of the old school, but by ingenious and resourceful production engineers, who were inspired by their chiefs to undertake and creditably to master the best way of producing attractive, efficient, and salable radio outfits. It is one of the instances that demonstrates that trade knowledge is much less essential to success than is the thorough production experience of technical engineers combined with a tremendous market demand for the product.

The First Steps

In May, 1928, a plant consisting of four buildings with approximately 375,000 sq. ft. of manufacturing floor space was leased from one of the General Motors subsidiaries in Chicago, and rapidly during the subsequent 60 days, woodworking machinery and equipment was installed, and the production of cabinets was under way while the previous tenants were moving out. By the first of July production had reached 1500 complete radio cabinets per day, which was increased at the rate of 500 per day every two or three weeks until by the first of September the maximum possible production of 3500 cabinets per day was reached.

A number of far-reaching decisions were made at this particular time, and the wisdom of these decisions has been fully justified by the subsequent success and efficiency of the cabinet plant In the first place although the plant, which was leased, contained the necessary dry kilns and storage space for handling rough lumber it was decided to purchase the lumber already dried and cut to the exact dimensions and size necessary for the particular cabinet designs which had already been decided upon. As this material is received in matched sets in each car, a great deal of storage space is saved because the parts can be started through the mill immediately upon receipt. The purchase of dimension stock makes necessary a rigid inspection of incoming materials, to be certain that each piece is exactly suitable for the particular part of the cabinet for which it is intended, and to eliminate at least half of the mill operations, allowing them to be performed nearer the sawmill in a cheaper labor market, thus saving freight on all waste material.

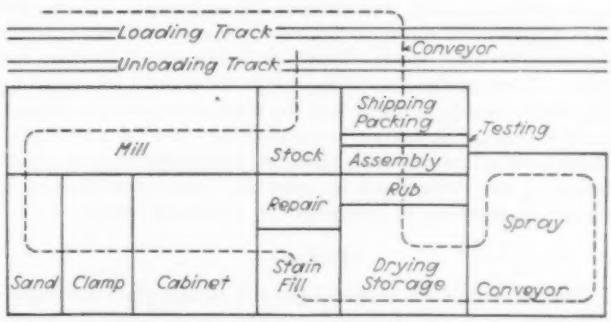


Fig. 1 Plant Layout of Grigsby-Grunow Company, Chicago, Ill.

Plywood specifications were also carefully developed so that the exact sizes required could be shipped in matched sets, and immediately be started through the manufacturing department, with a minimum amount of waste and machine work.

Sources of Supply

At the time these decisions were made there were no manufacturing units large enough to handle the quantity of material required so that specifications were scattered among a number of manufacturers. It soon became obvious that it was necessary to minimize the number of suppliers, and the best of the suppliers were inspired to increase their facilities to a point which in some cases meant three or four times their previous maximum production.

Every piece of material used in the cabinet is specified exactly, not only as to size and manufacturing tolerances, but as to kind and quality of wood, kind of glue used, amount of moisture, as well as other requirements.

Working with the plywood manufacturer reasonable limits were also developed for the veneer figures, so as not to limit the purchase of materials while still obtaining the beautiful effects necessary to make the cabinets a work of art.

This required close cooperation with the suppliers and a tremendous amount of work by all organizations, but this has been thoroughly justified by the results as evidenced by the fact that production was stepped up to 5000 units per day the first of May, 1929, without it becoming necessary to increase the number of suppliers or enlarge the plant.

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[1] Factory Manager, Grigsby-Grunow Co.

Presented at the Fourth National Meeting of the Wood Industries Division, Rockford, Ill., Oct. 16 to 18, 1929, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Plant Equipment

Inasmuch as the cabinets were designed before production was started, it was possible to select the exact equipment required to perform each operation, and to arrange so that this equipment would be in operation 22 hr. per day. The economy of this continuous operation is obvious. In the majority of cases the operators are working on the same piece and operation day after day, which makes for quality and low cost. Material is brought to them and taken from them in a steady flow, and in most cases passes through an inspection before moving from one department to the next for further operations. All material thrown out by the inspection department is taken to a separate department, and is either brought up to standard or discarded by this department. This eliminates all delays and congestion that would result from "backtracking" material for salvage in the manufacturing department. It also puts the salvaging under the supervision of an expert whose whole thought is to prevent waste of material.

All machines are individually driven by electric motors so that shafting and belts are entirely eliminated. This permits great flexibility in the arrangement of machines, preserves headroom for mechanical handling, distributes natural and artificial light more advantageously, and reduces dirt and noise. A complete blower system of the most improved type and ample capacity has been installed so that there is a minimum of shavings and dust. Every machine and operator in the plant is scheduled by the production department and the production of every department is checked each hour to see that the "rate" is maintained. Reports are submitted to the operating heads each hour, and upon failure of any department to make its "rate," investigation is started immediately to determine the cause and remedy.

Inspection

Ten per cent of the employees of the cabinet plant are inspectors reporting to a chief inspector, who reports only to the factory manager, and no foreman or department head other than the chief inspector and the factory manager is authorized to override the inspector's rejection. Inspection is based on the standards set up by the engineering department. It is obvious that it requires close cooperation between the production, operating, and inspection departments in order that harmonious relations, as well as the highest efficiency, be maintained. In all departments the battery system of production is used so that intensive supervision and intelligent inspection is possible.

Plant Layout

The various departments of the plant are classified as follows:

Stock Room. In this department is vested the responsibility for the unloading and storing of all raw and semi-raw materials used, and also from this department issue the "rations" of raw materials according to the time schedule set up by the production department.

Mill Room. This department is responsible for all necessary machine work, on dimension lumber and plywood.

Sanding Department. The work of this department is to polish (in the white) each part separately so that there is required the minimum amount of hand-sanding after assembly.

Clamp Department. In this department all individual parts are assembled and clamped into a case or cabinet.

Cabinet Room. Here all of the doors are fitted and hung, hardware put on, and all necessary hand finishing and sanding of molding, trim, etc., is done.

Finishing Department. To this department come all assembled units and parts in the "white," where they are stained, filled, sprayed, rubbed, and polished. Following this operation, each cabinet is inspected carefully, and is gone over by a trained finisher, and if found necessary, each cabinet is polished up by hand.

Assembly Department. The cabinet is then carefully re-inspected and turned over to the assembly department, where are installed the radio receiver, speaker, and hardware fittings on the exterior and in the interior of the cabinet.

Testing Department. The final test and inspection of the receiver and speaker after assembly are under the direction of the engineering department, and each completed job is checked carefully to see that every part functions properly.

Packing Department. The assembled and tested units are then turned over to the packing department, where the complete assembly is packed in a special packing case, and is again inspected and forwarded to the shipping department.

Shipping Department. In this department is installed a 1500-ft. mechanical conveyor which has a capacity for loading 35 cars per day.

Handling of Materials

All material is handled on trucks up to the clamp department, after which it is slid over specially prepared hardwood floors or carried by overhead conveyors from one operation to the next.

Warehouse Unnecessary

It is of interest that the manufacturers have no large warehouse for raw materials. A continuous inflow of materials is maintained and used at such a rate that many items of these materials are shipped out in the finished product within a few hours after they are received. Practically no item is kept in an unfinished state more than two days.

Volume Capacity

To the furniture manufacturer and woodworker, the figures below will be of interest. In the present production of 5000 radio sets per day approximately the following materials are used weekly:

18 carloads of plywood
18 carloads of dimension lumber
3 carloads of lacquer
1 carload of nails and screws
48 carloads of packing cases
5 tons of glue
2500 yards of silk grill cloth
150,000 lineal feet of molding

There are 40 cars required for each day's shipment of finished radio receivers.

A.S.M.E. Record and Index, 1930

THIS section of the Transactions contains a record of the Society's activities for the year 1930, together with an index of its publications. Since 1926 when the original form of printing the Transactions was abandoned, the Record and Index has been issued in book form. After further study of the publication program, the Council voted to issue the Record and Index so that it would be uniform in size and general appearance with other sections containing the technical papers, thus returning this material to the Transactions where it was formerly to be found. It thus becomes possible to bind the Record and Index with the technical papers for the use of libraries and official depositories throughout the world, and for members to file or bind their copies with the sections of Transactions they have received during the year.

The Record and Index Section of Transactions includes all the reference material likely to be of permanent value and of interest to future searchers. As an index it provides a means of locating the technical information in the Society's publications. It includes the separate indexes of the Transactions and *Mechanical Engineering*, together with a miscellaneous index to reports or other technical publications of the Society that have appeared during the year.

A considerable part of this section is devoted to memorial notices of members who have died during the year. Special care has been given to the preparation of the necrology with the idea in mind that fitting notice and attention should be given to significant events in the lives of deceased members, even though they may fall outside the immediate field of mechanical engineering.

F. V. LARKIN, *Chairman*
W. H. WINTERROWD
L. C. MORROW
S. F. VOORHEES
S. W. DUDLEY
Publications Committee

Charles Piez

THE career of Charles Piez, President of The American Society of Mechanical Engineers for the term 1929–1930, has been characteristically American. Born in Germany in 1866, of naturalized American parents, he grew up in this country and became a typical American. He personifies progressive Americanism of the sort typified by the late President Roosevelt. Mr. Piez received his technical education as a mining engineer at the School of Mines, Columbia University. Like many other men who later became leaders in the business world, his own earnings contributed largely toward paying for his education.

Immediately after his graduation in 1889, he entered the employ of the Link-Belt Engineering Company, in Philadelphia, as an engineer draftsman at $65 a month. Seventeen years later (in 1906), after he had attained to the position of chief engineer and general manager of the Philadelphia works of that concern, he was elected president of a consolidated organization of the three related companies, the Link-Belt Machinery Company (Chicago), the Ewart Manufacturing Company (Indianapolis), and the Link-Belt Engineering Company (Philadelphia). The consolidation was thereafter known as the Link-Belt Company. The consolidated corporation under Mr. Piez's management became widely known as an efficiently operated and successful engineering and manufacturing enterprise.

Largely as a result of his fame as an organizer and manager of industry, Mr. Piez was selected in November, 1917, to be vice-president and general manager of the United States Shipping Board Emergency Fleet Corporation, to carry out the nation's shipbuilding program. Charles M. Schwab, later chosen director-general of this corporation, "the greatest business organization in the world's history," and Mr. Piez were inseparable associates and friends in their titanic efforts to "bridge the seas with ships." On May 1, 1919, Mr. Piez resigned as director-general, to return to his private business. He continued as president of the Link-Belt Company until 1924, when he became chairman of the board, with full executive control of the company and its various subsidiaries.

He is also president of the Commercial Club of Chicago; a director of the State Bank of Chicago and of the Drexel State Bank of Chicago; a member of the executive committee of the Museum of Science and Industry founded by Julius Rosenwald; and a member of the following engineering societies: The American Society of Mechanical Engineers, American Institute of Mining and Metallurgical Engineers, Society of Naval Architects and Marine Engineers, and Western Society of Engineers.



CHARLES PIEZ

PRESIDENT OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
1929–1930

The American Society of Mechanical Engineers

THE personnel records and other information presented in this first section of the Record and Index refer, except where otherwise noted, as in the case of Local Section and Student Branch chairmen, to the official year beginning in December, 1929. Such information is purely of historical nature and is included here as a permanent record. For the names of those in office or serving the Society in any way in 1931, the Membership List for 1931 should be consulted.

Officers and Council

Dates in parentheses denote expiration of terms

PRESIDENT

CHARLES PIEZ

PAST-PRESIDENTS

W. F. DURAND (1930)
W. L. ABBOTT (1931)
C. M. SCHWAB (1932)
ALEX DOW (1933)
ELMER A. SPERRY[1] (1934)

VICE-PRESIDENTS

Terms expire December, 1930
R. L. DAUGHERTY
WM. ELMER
CHAS. E. GORTON

Terms expire December, 1931
PAUL DOTY
RALPH E. FLANDERS
ERNEST LEE JAHNCKE
CONRAD N. LAUER

MANAGERS

Terms expire December, 1930
FRED H. DORNER
W. A. HANLEY
HARVEY N. DAVIS

Terms expire December, 1931
CHARLES M. ALLEN
R. M. GATES
ELY C. HUTCHINSON

Terms expire December, 1932
HAROLD V. COES JAMES D. CUNNINGHAM C. F. HIRSHFELD

TREASURER

ERIK OBERG

SECRETARY

CALVIN W. RICE

ASSISTANT SECRETARIES

C. E. DAVIES ERNEST HARTFORD C. B. LEPAGE

EXECUTIVE COMMITTEE OF COUNCIL

CHARLES PIEZ, *Chairman*
CONRAD N. LAUER, *Vice-Chairman*
CALVIN W. RICE, *Secretary*
CHAS. E. GORTON
R. M. GATES
HAROLD V. COES

Advisory Members: Chairmen of the Finance Committee, the Local Sections Committee, and the Professional Divisions Committee.

CHAIRMEN OF STANDING COMMITTEES

Representatives on Council but without vote

Finance, F. A. SCHAFF, *Chairman*
DAVID LOFTS, *Vice-Chairman*
Meetings and Program, W. L. BATT
Publications, W. A. SHOUDY
Membership, L. K. COMSTOCK
Professional Divisions, J. W. ROE
Local Sections, THOMAS L. WILKINSON
Constitution and By-Laws, G. E. PFISTERER
Awards, ARTHUR M. GREENE, JR.
Relations with Colleges, SAMUEL H. LIBBY
Education and Training for Industries, R. L. SACKETT
Library, HENRY A. LARDNER
Research, ROBT. L. STREETER
Standardization, E. J. KEARNEY
Power Test Codes, F. R. LOW
Safety, H. W. MOWERY
Professional Conduct, JAMES E. SAGUE[2]

[1] Deceased June 16, 1930. In accordance with the Constitution, F. R. Low filled the vacancy, and the terms of the other past-presidents were extended by one year.

[2] Deceased May 9, 1930. John Hunter appointed to fill vacancy.

Standing Committees

Dates in parentheses denote expiration of terms

FINANCE

F. A. SCHAFF, *Chairman and Representative on Council* (1930)
DAVID LOFTS, *Vice-Chairman* (1932)
JAMES L. WALSH (1931)
K. L. MARTIN (1933)
JOHN H. LAWRENCE (1934)

Council Representatives:
WM. ELMER (1930)
HAROLD V. COES (1931)

MEETINGS AND PROGRAM

W. L. BATT, *Chairman and Representative on Council* (1930)
G. M. EATON (1931)
F. M. FEIKER (1932)
J. W. PARKER (1933)
COLLINS P. BLISS (1934)

PUBLICATIONS

W. A. SHOUDY, *Chairman and Representative on Council* (1930)
F. V. LARKIN (1931)
W. H. WINTERROWD (1932)
L. C. MORROW (1933)
S. F. VOORHEES (1934)

(*Personnel of Special Committee, p. 6*)

MEMBERSHIP

L. K. COMSTOCK, *Chairman and Representative on Council* (1930)
FREDERICK A. WALDRON (1931)
HENRY W. BUTLER (1932)
HOSEA WEBSTER (1933)
OTTO E. GOLDSCHMIDT (1934)

PROFESSIONAL DIVISIONS

J. W. ROE, *Chairman and Representative on Council* (1930)
H. W. BROOKS (1931)
W. F. DIXON (1932)
P. T. SOWDEN (1933)
C. B. PECK (1934)
ROBERT T. KENT, *Ex-Officio*
A. BLACK, *Ex-Officio*

(*Chairmen of Professional Divisions' Executive Committees, p. 7*)

LOCAL SECTIONS

THOMAS L. WILKINSON, *Chairman and Representative on Council* (1930)
HARRY R. WESTCOTT (1931)
CHARLES W. BENNETT (1932)
JAMES M. TODD (1933)
JILES W. HANEY (1934)

(*Chairmen of Local Sections' Executive Committees, p. 7*)

CONSTITUTION AND BY-LAWS

G. E. PFISTERER, *Chairman and Representative on Council* (1930)
A. D. BLAKE (1931)
THOS. C. MCBRIDE (1932)
R. S. NEAL (1933)
H. H. SNELLING (1934)

AWARDS

A. M. GREENE, JR., *Chairman and Representative on Council* (1934)
IRA N. HOLLIS[3] (1930)
H. L. SEWARD (1931)
ROY V. WRIGHT (1932)
K. H. CONDIT (1933)

RELATIONS WITH COLLEGES

SAMUEL H. LIBBY, *Chairman and Representative on Council* (1930)
M. C. MAXWELL (1931)
D. B. PRENTICE (1932)
E. F. CHURCH, JR. (1933)
W. L. ABBOTT (1934)

(*Student Branches and Honorary Chairmen, p. 7*)

EDUCATION AND TRAINING FOR THE INDUSTRIES

R. L. SACKETT, *Chairman and Representative on Council* (1934)
W. S. CONANT (1930)
DUGALD C. JACKSON (1931)
JOHN T. FAIG (1932)
HAROLD S. FALK (1933)

LIBRARY

HENRY A. LARDNER, *Chairman and Representative on Council* (1930)
ALTEN S. MILLER (1931)
GEO. F. BATEMAN (1932)
ELY C. HUTCHINSON (1933)
THE SECRETARY, CALVIN W. RICE

[3] Deceased August 15, 1930.

RESEARCH

Organized 1909, to supervise all research activities, collaborating with committees of kindred societies, and obtaining results of researches conducted in the U. S. and other countries

ROBT. L. STREETER, *Chairman and Representative on Council* (1930)
W. R. WEBSTER (1931) — ALEX. D. BAILEY (1933)
W. H. FULWEILER (1932) — A. A. POTTER (1934)

(*List of Research Committees and Publications, p. 12*)

STANDARDIZATION

Organized April, 1911, to supervise all standardization activities of the Society. Cooperates with American Standards Association

E. J. KEARNEY, *Chairman and Representative on Council* (1930)
H. BIRCHARD TAYLOR (1931) — WM. S. MONROE (1933)
L. K. SILLCOX (1932) — EARLE BUCKINGHAM (1934)

(*List of Standardization Committees and Publications, p. 12*)

POWER TEST CODES

Organized December, 1918, to revise and extend the Power Test Codes of the Society. The Codes had been formulated by various committees appointed from 1886 to that date

F. R. LOW, *Chairman and Representative on Council* (1930)

Terms expire 1930	*Terms expire 1931*
F. R. LOW	A. G. CHRISTIE
L. P. BRECKÉNRIDGE	P. DISERENS
R. H. FERNALD	C. E. LUCKE
C. F. HIRSHFELD	GEO. A. ORROK
R. J. S. PIGOTT	WM. MONROE WHITE

Terms expire 1932	*Terms expire 1933*
HARTE COOKE	E. H. BROWN
E. R. FISH	I. E. MOULTROP
O. P. HOOD	GEORGE A. HORNE
HENRY B. OATLEY	L. S. MARKS
W. J. WOHLENBERG	EDWARD N. TRUMP

Terms expire 1934

C. HAROLD BERRY — L. F. MOODY
FRANCIS HODGKINSON — E. B. RICKETTS
D. S. JACOBUS

(*List of Power Test Code Committees and Publications, p. 15*)

SAFETY

Appointed October, 1921, to extend knowledge of Safety, to promote cooperation in this field, and to supervise all safety code activities of Society except those of Boiler Code committee

H. W. MOWBRY, *Chairman and Representative on Council* (1933)
JOHN PRICE JACKSON (1930) — A. M. TODE (1932)
L. R. PALMER (1931) — T. A. WALSH, JR. (1934)

(*List of Safety Committees and Publications, p. 15*)

PROFESSIONAL CONDUCT

JAMES E. SAGUE,[4] *Chairman and Representative on Council* (1930)
JOHN HUNTER (1931) — A. G. CHRISTIE (1933)
W. B. POWELL (1932) — HERBERT S. PHILBRICK (1934)

Special Committees

REVENUES

W. L. BATT, *Chairman* — RALPH E. FLANDERS
JAMES D. CUNNINGHAM — CONRAD N. LAUER
DEXTER S. KIMBALL — ERIK OBERG
JAMES L. WALSH

BUDGET POLICY COMMITTEE

RALPH E. FLANDERS, *Chairman* — C. F. HIRSHFELD
J. D. CUNNINGHAM, *Vice-Chairman* — LEO LOEB
W. L. ABBOTT — HARRY R. WESTCOTT
HAROLD V. COES
ERIK OBERG, *Treasurer*
F. A. SCHAFF, *Chairman, Finance Committee*
W. L. BATT, *Chairman, Revenues Committee*

[4] Deceased May 9, 1930. John Hunter appointed to fill vacancy.

BIOGRAPHY ADVISORY COMMITTEE

F. R. LOW, *Chairman* — GEO. A. ORROK
ROY V. WRIGHT, *Vice-Chairman* — JOHN R. FREEMAN
RALPH E. FLANDERS

REGULAR NOMINATING COMMITTEE

GROUP	REPRESENTATIVE	ALTERNATE
I	RALPH EARLE	S. W. DUDLEY
II	VINCENT M. FROST, *Chairman*	W. W. MACON
III	WALTER F. DIXON	E. C. MAGDEBURGER
IV	EUGENE W. O'BRIEN, *Secretary*	THOMAS H. ALLEN JOHN M. FOSTER
V	C. SNELLING ROBINSON	JAMES H. HERRON
VI	JOHN HUNTER	MAX TOLTZ
VII	S. H. GRAF	A. H. T. WILLIAMS FRED'K G. BAENDER

LOCAL SECTIONS IN NOMINATING COMMITTEE GROUPS

GROUP I

BOSTON — NEW HAVEN
BRIDGEPORT — PROVIDENCE
GREEN MOUNTAIN — WATERBURY
HARTFORD — WESTERN MASSACHUSETTS
MERIDEN — WORCESTER
NEW BRITAIN

GROUP II

METROPOLITAN (N. Y.) AND FOREIGN MEMBERS

GROUP III

ANTHRACITE-LEHIGH VALLEY — ROCHESTER
BALTIMORE — SCHENECTADY
CENTRAL PENNSYLVANIA — SUSQUEHANNA
ONTARIO — SYRACUSE
PHILADELPHIA — UTICA
PLAINFIELD — WASHINGTON, D. C.

GROUP IV

ATLANTA — KNOXVILLE
BIRMINGHAM — MEMPHIS
CHARLOTTE — NEW ORLEANS
CHATTANOOGA — NORTH TEXAS
FLORIDA — RALEIGH
GREENVILLE — SAVANNAH
HOUSTON — VIRGINIA

GROUP V

AKRON — INDIANAPOLIS
BUFFALO — LOUISVILLE
CINCINNATI — PENINSULA
CLEVELAND — PITTSBURGH
COLUMBUS — TOLEDO
DAYTON — WEST VIRGINIA
DETROIT — YOUNGSTOWN
ERIE

GROUP VI

CHICAGO — ROCK RIVER VALLEY
KANSAS CITY — ST. JOSEPH VALLEY
MID-CONTINENT — ST. LOUIS
MILWAUKEE — ST. PAUL
MINNEAPOLIS — TRI-CITIES
NEBRASKA

GROUP VII

COLORADO — SAN FRANCISCO
INLAND EMPIRE — UTAH
LOS ANGELES — WESTERN WASHINGTON
OREGON

TELLERS OF ELECTION FOR OFFICERS

L. H. MORRISON — H. E. VEHSLAGE
GEO. A. ROBE

TELLERS ON AMENDMENTS

WINFIELD S. HUSON — WILLIAM A. GATELY
THOMAS H. NORMILE

ECONOMIC STATUS OF THE ENGINEER

Conrad N. Lauer, *Chairman*
C. F. Hirshfeld
Dexter S. Kimball
Wm. E. Wickenden
Henry B. Oatley
W. A. Starrett
H. L. Whittemore
James M. Todd, *representing Committee on Local Sections*

BOILER CODE

F. R. Low, *Chairman*
D. S. Jacobus, *Vice-Chairman*
C. W. Obert, *Honorary Secretary*
M. Jurist, *Acting Secretary*
H. E. Aldrich
Wm. H. Boehm
Frank S. Clark
Francis W. Dean
W. F. Durand
E. R. Fish
V. M. Frost
Chas. E. Gorton
Arthur M. Greene, Jr.
Frank B. Howell
Chas. L. Huston
J. O. Leech
LeRoy Mikels
Edward F. Miller
M. F. Moore
I. E. Moultrop
C. O. Myers
James Partington
C. L. Warwick
H. LeRoy Whitney

Honorary Members

Thomas E. Durban
William F. Kiesel, Jr.
H. H. Vaughan

(*List of Boiler Code Committees, p. 16*)

Professional Divisions

For complete personnel of executive and subcommittees consult 1930 Membership List

Division	Executive Committee Chairmen
Aeronautic	Charles H. Colvin
Applied Mechanics	S. Timoshenko
Fuels	John Van Brunt
Hydraulic	Wm. Monroe White
Iron and Steel	W. W. Macon
Machine-Shop Practice	W. J. Peets
Management	Chas. W. Lytle
Materials Handling	George E. Hagemann
National Defense	James L. Walsh
Oil and Gas Power	L. H. Morrison
Petroleum	W. G. Heltzel
Power	V. M. Frost
Printing Industries	E. P. Hulse
Railroad	A. F. Stuebing
Textile	Henry M. Burke
Wood Industries	Thomas D. Perry

Local Sections

For complete personnel for 1929–1930 and further information consult 1930 Membership List

Section	Executive Committee Chairmen[5]
Akron-Canton	F. S. Griffin
Anthracite-Lehigh Valley	F. L. Moore
Atlanta	C. T. Baker
Baltimore	F. A. Allner
Birmingham	G. H. Middlemiss
Boston	C. W. Conrad
Bridgeport	K. C. Monroe
Buffalo	C. E. Harrington
Central Pennsylvania	C. L. Allen
Charlotte	I. D. Kimball
Chattanooga	Newell Sanders
Chicago	H. S. Dickerson
Cincinnati	R. L. Rickwood
Cleveland	F. H. Vose
Colorado	F. H. Prouty
Columbus	H. M. Bush
Dayton	C. W. Ripsch
Detroit	E. W. Nicklin
Erie	G. B. Conrath
Florida	H. F. Greene, Jr.
Green Mountain	C. J. Dewell
Greenville	H. D. Learnard
Hartford	S. J. Teller
Houston	A. E. Hartwell
Indianapolis	W. M. Taylor
Inland Empire	U. B. Hough
Kansas City	A. L. Maillard
Knoxville	W. R. Woolrich
Los Angeles	L. W. Voorhees
Louisville	B. M. Brigman
Memphis	M. W. Rice
Meriden	K. W. Dechert
Metropolitan	A. A. Adler
Mid-Continent	A. J. Kerr
Milwaukee	W. C. Lindemann
Minneapolis	A. F. Moyer
Nebraska	B. J. Latimer
New Britain	H. S. Hall
New Haven	E. O. Waters
New Orleans	G. R. Hammett
North Texas	C. A. Cowles, Jr.
Norwich	Wm. H. Buck
Ontario	S. L. Fear
Oregon	G. O. Matter
Peninsula	F. H. Meyer
Philadelphia	H. A. Hoffer
Pittsburgh	S. Kneass
Plainfield	W. E. Wheaton
Providence	P. A. Merriam
Raleigh	J. M. Foster
Rochester	G. C. Van Vechten
Rock River Valley	J. H. Mansfield
St. Joseph Valley	C. C. Wilcox
St. Louis	W. E. Bryan
St. Paul	P. J. Frawley
San Francisco	R. L. Mahon
Savannah	L. C. Roesel
Schenectady	F. S. Bennett
Susquehanna	R. H. Irons
Syracuse	R. P. Lay
Toledo	C. V. Martin
Tri-Cities	W. P. Hunt
Utah	F. W. McEntire
Utica	Walter Clement
Virginia	V. Serbell
Washington, D. C.	H. I. Cone
Waterbury	H. Koester
Western Massachusetts	R. E. Newcomb
West Virginia	A. Hill
Western Washington	W. L. Dudley
Worcester	O. V. Payne
Youngstown	R. J. Wean

[5] Term of office, July, 1929–July, 1930.

Student Branches

For further information consult 1930 Membership List

Name and Location	Honorary Chairmen[6]
Akron, Univ. of, Akron, Ohio	F. S. Griffin
Alabama Polytechnic Inst., Auburn, Ala.	Solon Dixon
Arkansas, Univ. of, Fayetteville, Ark.	L. C. Price
Armour Inst. of Technology, Chicago, Ill.	Daniel Roesch
Brooklyn, Polytechnic Inst. of, Brooklyn	Joseph Lambertine
Brown Univ., Providence, R. I.	J. A. Hall
Bucknell Univ., Lewisburg, Pa.	Frank E. Burpee
California Inst. of Technology, Pasadena	W. H. Clapp
California, Univ. of, Berkeley, Calif.	H. B. Langille
Carnegie Inst. of Tech., Pittsburgh, Pa.	T. G. Estep
Case School of Applied Science, Cleveland	C. L. Tuve
Catholic Univ. of America, Washington	Wm. Karsunky
Cincinnati, Univ. of, Cincinnati, Ohio	C. A. Joerger
Clarkson College of Tech., Potsdam, N. Y.	Jess H. Davis
Clemson College, Clemson College, S. C.	C. P. Philpot
Colorado Agricultural College, Fort Collins	L. D. Crain
Colorado, Univ. of, Boulder, Colo.	Frank S. Bauer
Columbia Univ., New York, N. Y.	Carl F. Kayan
Cooper Union, New York, N. Y.	G. F. Bateman
Cornell Univ., Ithaca, N. Y.	S. S. Garrett
Delaware, Univ. of, Newark, Del.	R. L. Spencer
Detroit, Univ. of, Detroit, Mich.	F. J. Linsenmeyer
Drexel Inst., Philadelphia, Pa.	C. V. Hahn
Florida, Univ. of, Gainesville, Fla.	P. O. Yeaton

[6] In office December 31, 1930.

Name and Location	Honorary Chairmen
George Washington Univ., Washington, D. C.	Walter B. Lawrence
Georgia School of Technology Atlanta, Ga.	Ray M. Matson
Harvard Univ., Cambridge, Mass.[7]	
Idaho, Univ. of, Moscow, Idaho	Barton Cruikshank
Illinois, Univ. of, Urbana, Ill.	C. W. Ham
Iowa State College, Ames, Ia.	J. G. Hummel
Iowa, State Univ. of, Iowa City, Ia.	Ralph M. Barnes
Johns Hopkins Univ., Baltimore, Md.	F. W. Kouwenhoven
Kan. State Agricultural College, Manhattan	J. P. Calderwood
Kansas, Univ. of, Lawrence, Kan.	Ralph S. Tait
Kentucky, Univ. of, Lexington, Ky.	Carter C. Jett
Lafayette College, Easton, Pa.	Paul B. Eaton
Lehigh Univ., Bethlehem, Pa.	Fred V. Larkin
Louisiana State Univ., Baton Rouge, La.	Hamilton Johnson
Louisville, Univ. of, Louisville, Ky.	H. H. Fenwick
Lowell Textile Inst., Lowell, Mass.	H. J. Ball
Maine, Univ. of, Orono, Me.	Harry Watson
Marquette Univ., Milwaukee, Wis.	John E. Schoen
Mass. Inst. of Technology, Cambridge	C. E. Fuller
Michigan College of Mining and Technology, Houghton, Mich.	R. R. Seeber
Michigan State College, East Lansing, Mich.	Lawrence N. Field
Michigan, Univ. of, Ann Arbor, Mich.	R. S. Hawley
Minnesota, Univ. of, Minneapolis, Minn.	B. J. Robertson
Mississippi A. & M. College, A. & M. College	O. D. M. Varnado
Missouri School of Mines and Metallurgy, Rolla, Mo.	R. O. Jackson
Missouri, Univ. of, Columbia, Mo.	G. D. Newton
Montana State College, Bozeman, Mont.	Eric Therkelsen
Nebraska, Univ. of, Lincoln, Neb.	A. A. Luebs
Nevada, Univ. of, Reno, Nev.	F. H. Sibley
Newark College of Engineering, Newark, N. J.	J. Ansel Brooks
New Hampshire, Univ. of, Durham, N. H.	Edward T. Donovan
New York, College of City of, New York	Frederick Kuhlen
New York Univ., New York, N. Y.	Arthur C. Coonradt
North Carolina State College, Raleigh, N. C.	J. M. Foster
North Carolina, Univ. of, Chapel Hill, N. C.	E. G. Hoefer
North Dakota Agri. College, Fargo, N. D.	Robert M. Dolve
North Dakota, Univ. of, Grand Forks, N. D.	A. J. Diakoff
Northeastern Univ., Boston, Mass.	J. W. Zeller
Notre Dame, Univ. of, Notre Dame, Ind.	(To be appointed)
Ohio Northern Univ., Ada, Ohio	John A. Needy
Ohio State Univ., Columbus, Ohio	W. T. Magruder
Oklahoma A. & M. College, Stillwater, Okla.	E. C. Baker
Oklahoma, Univ. of, Norman, Okla.	J. H. Felgar
Oregon State Agricultural College, Corvallis	R. E. Summers
Pennsylvania State College, State College	C. L. Allen
Pennsylvania, Univ. of, Philadelphia, Pa.	John A. Prior
Pittsburgh, Univ. of, Pittsburgh, Pa.	John A. Dent
Porto Rico, Univ. of, Mayaguez, P. R.	Ramon Gil
Pratt Inst., Brooklyn, N. Y.	A. C. Harper
Princeton Univ., Princeton, N. J.	A. M. Greene, Jr.
Purdue Univ., W. Lafayette, Ind.	H. L. Solberg
Rensselaer Polytechnic Inst., Troy, N. Y.	Howard E. Stevens
Rhode Island State College, Kingston, R. I.	Royal L. Wales
Rice Inst., Houston, Tex.	J. V. Pennington
Rose Polytechnic Inst., Terre Haute, Ind.	Carl Wischmeyer
Rutgers Univ., New Brunswick, N. J.	H. Lea Mason
Santa Clara, Univ. of, Santa Clara, Calif.	G. L. Sullivan
Southern California, Univ. of, Los Angeles	T. T. Eyre
Stanford Univ., Stanford University, Calif.	A. B. Domonoske
Stevens Inst. of Technology, Hoboken, N. J.	F. D. Furman
Swarthmore College, Swarthmore, Pa.	G. A. Bourdelais
Syracuse Univ., Syracuse, N. Y.	S. T. Hart
Tennessee, Univ. of, Knoxville, Tenn.	Leo Holdridge
Texas, A. & M. College of, College Station	V. M. Faires
Texas Technological College, Lubbock, Tex.	C. L. Svensen
Texas, Univ. of, Austin, Tex.	Carl J. Eckhardt
Tufts College, Tufts College, Mass.	W. E. Farnham
U. S. Naval Academy, P. G. Sch., Annapolis	P. J. Kiefer
Utah, Univ. of, Salt Lake City, Utah	W. J. Cope
Vanderbilt Univ., Nashville, Tenn.	P. A. Cushman
Vermont, Univ. of, Burlington, Vt.	E. L. Sussdorff
Villanova College, Villanova, Pa.	J. S. Morehouse
Virginia Polytechnic Inst., Blacksburg, Va.	J. B. Jones
Virginia, Univ. of, Charlottesville, Va.	A. F. Macconochie
Washington, State College of, Pullman, Wash.	Howard H. Langdon
Washington Univ., St. Louis, Mo.	Edward H. Sager
Washington, Univ. of, Seattle, Wash.	R. H. G. Edmonds
West Virginia Univ., Morgantown, W. Va.	C. R. Jones
Wisconsin, Univ. of, Madison, Wis.	J. W. McNaul
Worcester Polytechnic Inst., Worcester	Kenneth G. Merriam
Wyoming, Univ. of, Laramie, Wyo.	Robt. Rhoads
Yale Univ., New Haven, Conn.	S. W. Dudley

[7] Established November, 1930.

A.S.M.E. Representatives on Joint Activities

Dates in parentheses denote expiration of term

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

SECTION M, ENGINEERING

James H. Herron — M. P. Cleghorn

Representatives or alternates appointed according to geographical location of meetings

AMERICAN ENGINEERING COUNCIL

Terms expire January 1, 1931	*Terms expire January 1, 1932*
D. Robert Yarnall, *Vice-Chairman*, Philadelphia, Pa.	Charles Piez, *Chairman*, Chicago, Ill.
E. O. Eastwood, Seattle, Wash.	L. P. Alford, New York, N. Y.
Dean E. Foster, Tulsa, Okla.	Thomas D. Campbell, Hardin, Mont.
O. P. Hood, Washington, D. C.	William B. Ferguson, Newport News, Va.
W. P. Hunt, Moline, Ill.	Charles E. Ferris, Knoxville, Tenn.
Charles Penrose, Philadelphia, Pa.	John Lyle Harrington, Kansas City, Mo.
Frank A. Scott, Cleveland, Ohio	William H. Kenerson, Providence, R. I.
Elmer A. Sperry, Brooklyn, N. Y.	John H. Lawrence, New York, N. Y.
Max Toltz, St. Paul, Minn.	Richard C. Marshall, Jr., Chicago, Ill.
Edward N. Trump, Syracuse, N. Y.	A. A. Potter, Lafayette, Ind.

AMERICAN SOCIETY OF SAFETY ENGINEERS

ENGINEERING SECTION, NATIONAL SAFETY COUNCIL

H. W. Mowery — Ernest Hartford

AMERICAN STANDARDS ASSOCIATION

Cloyd M. Chapman (1930) — H. Birchard Taylor (1932)
Collins P. Bliss (1931)[8] — K. H. Condit (*alternate*)
C. B. LePage (*alternate*)

ENGINEERING FOUNDATION, INC.

Formerly United Engineering Society

E. R. Fish (1931) — H. Hobart Porter (1932)
Harold V. Coes (1933)

ENGINEERING SOCIETIES RESEARCH BOARD

D. Robert Yarnall (1931) — H. Hobart Porter (1932)[9]
A. E. White (1933)

GANTT MEDAL BOARD OF AWARD

W. L. Conrad — Conrad N. Lauer
Dexter S. Kimball

GUGGENHEIM MEDAL BOARD OF AWARD

Elmer A. Sperry[10] (May, 1931) — Edwin E. Aldrin (May, 1933)
W. F. Durand (May, 1932) — George W. Lewis (May, 1934)

HERBERT HOOVER MEDAL BOARD OF AWARD

Ambrose Swasey — Dexter S. Kimball
Calvin W. Rice

INTERNATIONAL ELECTROTECHNICAL COMMISSION

U. S. NATIONAL COMMITTEE

F. R. Low — C. Harold Berry
W. F. Durand — H. Birchard Taylor
Francis Hodgkinson

[8] Represents the A.S.M.E. on the Executive Committee of the A.S.A.
[9] A.S.M.E. representative from Board of Trustees of Engineering Foundation, Inc.
[10] Deceased, June 16, 1930. H. I. Cone appointed to fill vacancy.

JOHN FRITZ MEDAL BOARD OF AWARD

The terms of office expire in October of each year

DEXTER S. KIMBALL (1930) — ALEX DOW (1932)
C. M. SCHWAB (1931) — ELMER A. SPERRY (1933)[11]

JOSEPH A. HOLMES SAFETY ASSOCIATION

O. P. HOOD

NATIONAL RESEARCH COUNCIL

DIVISION OF ENGINEERING

B. H. BLOOD (June, 1930) — R. J. S. PIGOTT (June, 1931)
A. E. WHITE (June, 1932)

ALFRED NOBLE PRIZE

L. P. ALFORD

SPIRIT OF ST. LOUIS MEDAL BOARD OF AWARD

(To be appointed)

WESTERN SOCIETY OF ENGINEERS

WASHINGTON AWARD

CHARLES PIEZ (June, 1930) — J. D. CUNNINGHAM (June, 1931)

[11] Deceased, June 16, 1930. W. L. Abbott appointed to fill vacancy.

GENERAL ASSIGNMENTS[12]

American Bureau of Welding, Advisory Board of the National Research Council, JAMES PARTINGTON.
American Bureau of Welding, Advisory Committee on Structural Steel Welding, GEO. A. ORROK.
American Bureau of Welding, Gas Welding Committee, JAMES PARTINGTON and C. W. OBERT.
George Washington Bicentennial Commission, GANO DUNN.
International High Commission, Advisory Committee to the U. S. Section, concerned with a preliminary study and compilation of a report on the use of Uniform Weights and Measures, RALPH E. FLANDERS.
National Screw Thread Commission, LUTHER D. BURLINGAME.
Standardization Survey Committee, C. M. SCHWAB, H. BIRCHARD TAYLOR (alternate).
U. S. Department of Commerce, National Committee on Metals Utilization, STANLEY G. FLAGG, JR.
U. S. Department of Commerce, National Conference on Street and Highway Safety, E. J. POSSELT.
U. S. Shipping Board, Fuel Conservation Board, H. L. SEWARD.

[12] The Society is also represented on a number of technical committees sponsored by other organizations. These committees are listed as follows: Research, p. 12; Standardization, p. 14; Safety, p. 15.

Honorary Members

HONORARY MEMBERS IN PERPETUITY

ALEXANDER LYMAN HOLLEY, Founder of the Society. Died 1882.
JOHN EDSON SWEET, Founder of the Society. Died 1916.
HENRY ROSSITER WORTHINGTON, Founder of the Society. Died 1880.

DECEASED HONORARY MEMBERS

	ELECTED	DIED
HORATIO ALLEN	1880	1889
SIR WILLIAM ARROL	1905	1913
SIR BENJAMIN BAKER	1886	1907
JOHANN BAUSCHINGER	1884	1893
SIR HENRY BESSEMER	1891	1898
SIR FREDERICK JOSEPH BRAMWELL	1884	1903
JOHN ALFRED BRASHEAR	1908	1920
GUSTAVE CANET	1900	1908
ANDREW CARNEGIE	1907	1919
DANIEL KINNEAR CLARK	1882	1896
RUDOLPH JULIUS EMMANUEL CLAUSIUS	1882	1888
SIR JOHN COODE	1889	1892
PETER COOPER	1882	1883
CARL GUSTAF PATRIK DE LAVAL	1912	1913
RUDOLPH DIESEL	1912	1913
JAMES DREDGE	1886	1906
VICTOR DWELSHAUVERS-DERY	1886	1913
ALEXANDRE GUSTAVE EIFFEL	1889	1923
MARSHAL FERDINAND FOCH	1921	1929
SIR CHARLES DOUGLAS FOX	1900	1921
JOHN FRITZ	1900	1913
MAJOR - GENERAL GEORGE WASHINGTON GOETHALS	1917	1928
FRANZ GRASHOF	1884	1893
OTTO HALLAUER	1882	1883
CHARLES HAYNES HASWELL	1905	1907
FRIEDRICH GUSTAV HERRMANN	1884	1907
GUSTAV ADOLPH HIRN	1882	1890
JOSEPH HIRSCH	1889	1901
IRA N. HOLLIS	1928	1930
ROBERT WOOLSTON HUNT	1920	1923
BENJAMIN FRANKLIN ISHERWOOD	1894	1915
HENRI LÉAUTÉ	1891	1916
ERASMUS DARWIN LEAVITT	1915	1916
ANATOLE MALLET	1912	1919
CHARLES H. MANNING	1913	1919
REAR-ADMIRAL GEORGE WALLACE MELVILLE	1910	1912
CHARLES TALBOT PORTER	1890	1910
AUGUSTE C. E. RATEAU	1919	1930
SIR EDWARD J. REED	1882	1906
FRANZ REULEAUX	1882	1905
HENRI ADOLPHE - EUGENE SCHNEIDER	1882	1898
C. WILLIAM SIEMANS	1882	1883
HENRY ROBINSON TOWNE	1921	1924
HENRI TRESCA	1882	1885
FRANCIS A. WALKER	1886	1897
WORCESTER REED WARNER	1925	1929
SIR WILLIAM HENRY WHITE	1900	1913
GEORGE WESTINGHOUSE	1897	1914

LIVING HONORARY MEMBERS

	ELECTED
SIR JOHN AUDLEY FREDERICK ASPINALL	1911
WILLIAM WALLACE ATTERBURY	1925
MORTIMER ELWYN COOLEY	1928
CHARLES DE FRÉMINVILLE	1919
THOMAS ALVA EDISON	1904
REAR-ADMIRAL ROBERT STANISLAUS GRIFFIN	1920
NATHANAEL GREENE HERRESHOFF	1921
HONORABLE HERBERT CLARK HOOVER	1925
MASAWO KAMO	1929
HENRI LE CHATELIER	1927
THE HONORABLE SIR CHARLES ALGERNON PARSONS	1920
GRANDE UFFICIALE ING. PIO PERRONE	1920
CHARLES M. SCHWAB	1918
VISCOUNT EIICHI SHIBUSAWA	1929
AMBROSE SWASEY	1916
ELIHU THOMSON	1930
WILLIAM CAWTHORNE UNWIN	1898
SAMUEL MATTHEWS VAUCLAIN	1920
OSKAR VON MILLER	1912
RIGHT HONORABLE LORD WEIR	1920
ORVILLE WRIGHT	1918
SIR ALFRED FERNANDEZ YARROW	1914

Past Officers

ALEXANDER LYMAN HOLLEY, Chairman of the Preliminary Meeting for Organization of The American Society of Mechanical Engineers. Died January 29, 1882

PRESIDENTS

1880–1882	ROBERT HENRY THURSTON	Died October 25, 1903
1883	ERASMUS DARWIN LEAVITT	Died March 11, 1916
1884	JOHN EDSON SWEET	Died May 8, 1916
1885	JOSEPHUS FLAVIUS HOLLOWAY	Died September 1, 1896
1886	COLEMAN SELLERS	Died December 28, 1907
1887	GEORGE H. BABCOCK	Died December 16, 1893
1888	HORACE SEE	Died December 14, 1909
1889	HENRY ROBINSON TOWNE	Died October 15, 1924
1890	OBERLIN SMITH	Died July 19, 1926
1891	ROBERT WOOLSTON HUNT	Died July 11, 1923
1892	CHARLES HARDING LORING	Died February 5, 1907
1893–1894	ECKLEY BRIXTON COXE	Died May 13, 1895
1895	EDWARD F. C. DAVIS	Died August 6, 1895
1895	CHARLES ETHAN BILLINGS	Died June 4, 1920
1896	JOHN FRITZ	Died February 13, 1913
1897	WORCESTER REED WARNER	Died June 25, 1929
1898	CHARLES WALLACE HUNT	Died March 27, 1911
1899	GEORGE WALLACE MELVILLE	Died March 17, 1912
1900	CHARLES HILL MORGAN	Died January 10, 1911
1901	SAMUEL T. WELLMAN	Died July 11, 1919
1902	EDWIN REYNOLDS	Died February 19, 1909
1903	JAMES MAPES DODGE	Died December 4, 1915
1904	AMBROSE SWASEY	Cleveland, Ohio
1905	JOHN RIPLEY FREEMAN	Providence, R. I.
1906	FREDERICK WINSLOW TAYLOR	Died March 21, 1915
1907	FREDERICK REMSEN HUTTON	Died May 14, 1918
1908	MINARD LAFEVER HOLMAN	Died January 4, 1925
1909	JESSE MERRICK SMITH	Died April 1, 1927
1910	GEORGE WESTINGHOUSE	Died March 12, 1914
1911	EDWARD DANIEL MEIER	Died December 15, 1914
1912	ALEXANDER CROMBIE HUMPHREYS	Died August 14, 1927
1913	WILLIAM FREEMAN MYRICK GOSS	Died March 23, 1928
1914	JAMES HARTNESS	Springfield, Vt.
1915	JOHN ALFRED BRASHEAR	Died April 8, 1920
1916	DAVID SCHENCK JACOBUS	New York, N. Y.
1917	IRA NELSON HOLLIS	Died August 15, 1930
1918	CHARLES THOMAS MAIN	Boston, Mass.
1919	MORTIMER ELWYN COOLEY	Ann Arbor, Mich.
1920	FRED J. MILLER	Center Bridge, Pa.
1921	EDWIN S. CARMAN	Cleveland, Ohio
1922	DEXTER SIMPSON KIMBALL	Ithaca, N. Y.
1923	JOHN LYLE HARRINGTON	Kansas City, Mo.
1924	FREDERICK ROLLINS LOW	New York, N. Y.
1925	WILLIAM FREDERICK DURAND	Stanford Univ., Calif.
1926	WILLIAM LAMONT ABBOTT	Chicago, Ill.
1927	CHARLES M. SCHWAB	New York, N. Y.
1928	ALEX DOW	Detroit, Mich.
1929	ELMER AMBROSE SPERRY	Died June 16, 1930
1930	CHARLES PIEZ	Chicago, Ill.

NOTE: According to the Constitution, Article C7, Sec. 2, the last five surviving Past-Presidents are members of the Council.

VICE-PRESIDENTS

HENRY ROSSITER WORTHINGTON	April, 1880–December, 1880
COLEMAN SELLERS	April, 1880–November, 1881
ECKLEY B. COXE	April, 1880–November, 1881
QUINCY A. GILMORE	April, 1880–December, 1880
WM. H. SHOCK	April, 1880–November, 1882
ALEXANDER L. HOLLEY	April, 1880–January, 1882
FRANCIS A. PRATT	December, 1880–November, 1881
THEO. N. ELY	1881–November, 1882
WASHINGTON JONES	1881–November, 1882
WM. P. TROWBRIDGE	1881–November, 1883
E. D. LEAVITT	1881–December, 1882
CHAS. E. EMERY	1881–1883
S. B. WHITING	1882–1883
JOHN FRITZ	1882–1884
HENRY MORTON	1882–1884
WM. METCALF	1882–1884
A. B. COUCH	1883–1885
W. R. ECKART	1883–1885
J. V. MERRICK	1883–1885
CHAS. W. COPELAND	1884–1886
HENRY R. TOWNE	1884–1886
COLEMAN SELLERS	1884–1885
OLIN H. LANDRETH	1885–1886
ALLAN STIRLING	1885–1887
HORACE SEE	1885–1887
CHAS. H. LORING	1885–1887
JOS. MORGAN, JR.	1886–1888
CHAS. T. PORTER	1886–1888
HORACE S. SMITH	1886–1888
W. S. G. BAKER	1887–1889
H. G. MORRIS	1887–1889
C. J. H. WOODBURY	1887–1889
THOS. J. BORDEN	1888–1890
WILLIAM KENT	1888–1890
CHARLES B. RICHARDS	1888–1890
DE VOLSON WOOD	1889–1891
JOEL SHARP	1889–1891
GEO. W. WEEKS	1889–1891
STEPHEN W. BALDWIN	1890–1892
ALEX. GORDON	1890–1892
JNO. F. PARKHURST	1890–1892
GEORGE I. ALDEN	1891–1893
E. F. C. DAVIS	1891–1893
IRVING M. SCOTT	1891–1893
CHARLES WALLACE HUNT	1892–1894
EDWIN REYNOLDS	1892–1894
THOS. R. PICKERING	1892–1894
PERCIVAL ROBERTS, JR.	1893–1895
H. J. SMALL	1893–1895
CHARLES E. BILLINGS	1893–1895
FRANK H. BALL	1894–1896
M. L. HOLMAN	1894–1896
JESSE M. SMITH	1894–1896
FRANCIS W. DEAN	1895–1897
CHARLES H. MANNING	1895–1897
GEORGE W. MELVILLE	1895–1897
EDWIN S. CRAMP	1896–1898
W. F. DURFEE	1896–1898
S. T. WELLMAN	1896–1898
CHARLES M. JARVIS	1897–1899
WALTER S. RUSSEL	1897–1899
JOHN C. KAFER	1897–1899
E. D. MEIER	1898–1900
GEORGE R. STETSON	1898–1900
B. H. WARREN	1898–1900
JESSE M. SMITH	1899–1901
STEVENSON TAYLOR	1899–1901
DAVID TOWNSEND	1899–1901
JAMES M. DODGE	1900–1902
AMBROSE SWASEY	1900–1902
ARTHUR M. WAITT	1900–1902
M. E. COOLEY	1901–1903
WILFRED LEWIS	1901–1903
M. P. HIGGINS	1901–1903
JAMES CHRISTIE	1902–1904
F. H. DANIELS	1902–1904
JOHN R. FREEMAN	1902–1904
D. S. JACOBUS	1903–1905
WILLIAM J. KEEP	1903–1905
M. L. HOLMAN	1903–1905
S. M. VAUCLAIN	1904–1906
H. H. WESTINGHOUSE	1904–1906
FRED. W. TAYLOR	1904–1905
GEO. W. BARRUS	1905–1906
WALTER M. MCFARLAND	1905–1907
ROBT. C. MCKINNEY	1905–1907
EDWARD N. TRUMP	1905–1907
PHILETUS W. GATES	1906–1908
JOHN W. LIEB, JR.	1906–1908
ALEX DOW	1906–1908
L. P. BRECKENRIDGE	1907–1909
FRED J. MILLER	1907–1909
ARTHUR WEST	1907–1909
GEO. M. BOND	1908–1910
R. C. CARPENTER	1908–1910
F. M. WHYTE	1908–1910
CHAS. WHITING BAKER	1909–1911
W. F. M. GOSS	1909–1911
E. D. MEIER	1909–1910
ALEX. C. HUMPHREYS	1910–1911
GEO. M. BRILL	1910–1912
EDWIN M. HERR	1910–1912
HENRY H. VAUGHAN	1910–1912
WM. F. DURAND	1911–1913
IRA N. HOLLIS	1911–1913
THOS. B. STEARNS	1911–1913
I. E. MOULTROP	1912–1914
HENRY G. STOTT	1912–1914
JAMES HARTNESS	1912–1913
E. B. KATTE	1913–1914

H. L. Gantt 1913–1915
E. E. Keller 1913–1915
H. G. Reist 1913–1915
Henry Hess 1914–1916
Geo. W. Dickie 1914–1916
James E. Sague 1914–1916
Wm. B. Jackson 1915–1917
J. Sellers Bancroft 1915–1917
Julian Kennedy 1915–1917
Charles H. Benjamin 1916–1918
Arthur M. Greene, Jr. 1916–1918
Charles T. Plunkett 1916–1918
Spencer Miller 1917–1919
Max Toltz 1917–1919
John Hunter 1917–1919
Fred R. Low 1918–1920
Henry B. Sargent 1918–1920
John A. Stevens 1918–1920
John R. Allen[13] 1920–1921
William B. Gregory[14] 1920–1921
Robert H. Fernald 1919–1921
Edward C. Jones 1919–1921
Leon P. Alford 1920–1922
John L. Harrington 1920–1922
Robert B. Wolf 1920–1922
E. A. Deeds 1921–1923
Robert Sibley 1921–1923
L. E. Strothman[15] 1921–1922
Arthur L. Rice[16] 1922
H. H. Vaughan[17] 1923
Walter S. Finlay, Jr. 1922–1924
Wm. H. Kenerson 1922–1924
Earl F. Scott 1922–1924
George I. Rockwood 1923–1925
W. J. Sando 1923–1925
H. Birchard Taylor 1923–1925
Robert W. Angus 1924–1926
Sherwood F. Jeter 1924–1926
Thos. L. Wilkinson 1924–1926
A. G. Christie 1925–1927
Wm. T. Magruder 1925–1927
Roy V. Wright 1925–1927
H. V. Coes[18] 1927
Charles L. Newcomb 1926–1928
E. O. Eastwood 1926–1928
Edwards R. Fish 1926–1928
John H. Lawrence 1927–1929
E. A. Muller 1927–1929
Newell Sanders 1927–1929
Paul Wright 1927–1929
Robert L. Daugherty 1928–1930
William Elmer 1928–1930
Charles E. Gorton 1928–1930
Paul Doty 1929–1931
Ernest L. Jahncke 1929–1931
Conrad N. Lauer 1929–1931
Ralph E. Flanders 1929–1931

MANAGERS

Wm. P. Trowbridge
April, 1880–November, 1881
Theo. N. Ely . April, 1880–November, 1881
J. C. Hoadley . April, 1880–November, 1881
Washington Jones
April, 1880–November, 1881
Wm. B. Cogswell
April, 1880–November, 1882
Chas. B. Richards
April, 1880–November, 1882
S. B. Whiting . April, 1880–November, 1882
E. D. Leavitt, Jr.
April, 1880–November, 1882
J. F. Holloway
November, 1880–November, 1883
Geo. W. Fisher
November, 1880–November, 1883
Allan Stirling
November, 1881–November, 1884
Geo. H. Babcock
1881–November, 1884
S. W. Robinson . . 1881–November, 1884
John E. Sweet 1882–1883
Robt. W. Hunt 1882–1885
Chas. T. Porter 1882–1885
C. J. H. Woodbury 1882–1885
W. F. Durfee 1883–1886
Oberlin Smith 1883–1886
C. C. Worthington 1883–1886
Wm. Lee Church 1884–1887
Wm. Hewitt 1884–1887
Chas. H. Morgan 1884–1887
Hamilton A. Hill 1885–1888
William Kent 1885–1888
Saml. T. Wellman 1885–1888
John T. Hawkins 1886–1889
Fredk. G. Coggin 1886–1889
Thos. R. Morgan, Sr. 1886–1889
Stephen W. Baldwin 1887–1890
Fredk. Grinnell 1887–1890
Morris Sellers 1887–1890
Frank H. Ball 1888–1891
Geo. M. Bond 1888–1891
Wm. Forsyth 1888–1891
Jas. E. Denton 1889–1892
Carleton W. Nason 1889–1892
H. H. Westinghouse 1889–1892
Andrew Fletcher 1890–1893
Worcester R. Warner 1890–1893
Coleman Sellers, Jr. 1890–1893
Jas. M. Dodge 1891–1894
Robt. Forsyth 1891–1894
Jesse M. Smith 1891–1894
John Thompson 1892–1895
Charles W. Pusey 1892–1895
Charles H. Manning 1892–1895
John B. Herreshoff 1893–1896
Lebbeus B. Miller 1893–1896
Walter S. Russel 1893–1896
Charles A. Bauer 1894–1897
Arthur C. Walworth 1894–1897
John C. Kafer 1894–1897
Geo. W. Dickie 1895–1898
E. D. Meier 1895–1898
Norman C. Stiles 1895–1898
A. Wells Robinson 1896–1899
H. S. Haines 1896–1899
G. C. Henning 1896–1899
J. B. Stanwood 1897–1900
H. H. Suplee 1897–1900
Geo. Richmond 1897–1900
Edgar C. Felton 1898–1901
A. M. Goodale 1898–1901
Richard H. Soule 1898–1901
Francis H. Boyer 1899–1902
John A. Brashear 1899–1902
Alfred H. Raynal 1899–1902
W. F. M. Goss 1900–1903
D. S. Jacobus 1900–1903
De Courey May 1900–1903
Charles H. Corbett 1901–1904
H. A. Gillis 1901–1904
R. S. Moore 1901–1904
Robert C. McKinney 1902–1905
Newell Sanders 1902–1905
S. S. Webber 1902–1905
John W. Lieb, Jr. 1903–1906
Asa M. Mattice 1903–1906
Geo. I. Lockwood 1903–1906
George M. Brill 1904–1907
Fred J. Miller 1904–1907
Richard H. Rice 1904–1907
Walter Laidlaw 1905–1908
Fred. M. Prescott 1905–1908
Frank G. Tallman 1905–1908
G. M. Basford 1906–1909
Andrew J. Caldwell 1906–1909
Andrew L. Riker 1906–1909
Wm. L. Abbott 1907–1910
Alex. C. Humphreys 1907–1910
Henry G. Stott 1907–1910
H. L. Gantt 1908–1911
I. E. Moultrop 1908–1911
W. J. Sando 1908–1911
J. Sellers Bancroft 1909–1911
James Hartness 1909–1912
H. G. Reist 1909–1912
Henry G. Stott 1911–1912
D. F. Crawford 1910–1913
Stanley G. Flagg, Jr. 1910–1913
E. B. Katte 1910–1913
Charles J. Davidson 1911–1914
Henry Hess 1911–1914
George A. Orrok 1911–1914
Alfred Noble 1912–1914
Morris L. Cooke 1914–1915
W. B. Jackson 1912–1915
H. M. Leland 1912–1915
Arthur M. Greene, Jr. 1913–1916
John Hunter 1913–1916
Elliott H. Whitlock 1913–1916
Charles T. Main 1914–1917
Spencer Miller 1914–1917
Max Toltz 1914–1917
John H. Barr 1915–1918
H. de B. Parsons 1915–1918
John A. Stevens 1915–1918
Robert H. Fernald 1916–1919
William B. Gregory 1916–1919
C. R. Weymouth 1916–1919
Fred A. Geier 1917–1920
Fred. N. Bushnell 1917–1920
D. Robert Yarnall 1917–1920
Charles L. Newcomb 1918–1921
Charles Russ Richards 1918–1921
Frank O. Wells 1918–1921
Elbert C. Fisher 1919–1922
Earl F. Scott 1919–1922
Dexter S. Kimball 1919–1921
L. C. Nordmeyer 1920–1923
Henry M. Norris 1920–1923
Carl C. Thomas 1920–1923
Sherwood F. Jeter 1921–1924
Horace P. Liversidge 1921–1924
Hollis P. Porter 1921–1924
A. G. Christie 1922–1925
James H. Herron 1922–1925
Roy V. Wright 1922–1925
E. O. Eastwood 1923–1926
E. R. Fish 1923–1926
Frank A. Scott 1923–1926
John H. Lawrence 1924–1927
Edward A. Muller 1924–1927
Paul Wright 1924–1927
Robt. L. Daugherty 1925–1928
Wm. Elmer 1925–1928
Chas. E. Gorton 1925–1928
Paul Doty 1926–1929
Ralph E. Flanders 1926–1929
Conrad N. Lauer 1926–1929
Frederick H. Dorner 1927–1930
William A. Hanley 1927–1930
L. B. McMillan[19] 1927–1929
Harvey N. Davis[20] 1929–1930
Charles M. Allen 1928–1931
Robert M. Gates 1928–1931
Ely C. Hutchinson 1928–1931
James D. Cunningham 1929–1932
Clarence F. Hirshfeld 1929–1932
Harold V. Coes 1929–1932

[13] Deceased, October 26, 1920.
[14] Elected to fill unexpired term of John R. Allen.
[15] Deceased, May 8, 1922.
[16] Elected to fill vacancy caused by death of L. E. Strothman.
[17] Elected to complete term of L. E. Strothman, deceased.
[18] Under Amendments to Constitution, providing for seven Vice-Presidents (formerly only six).
[19] Deceased, August 10, 1929.
[20] Elected to fill unexpired term of L. B. McMillan.

TREASURERS

Lycurgus B. Moore	April, 1880–December, 1881
Chas. W. Copeland	December, 1881–November, 1884
William H. Wiley	1884–1925
Erik Oberg	1925–date

SECRETARIES

Sam S. Webber, Jr.	Secretary, Organization Meeting, 1880
Lycurgus B. Moore	Acting Secretary, April–November, 1880
Thos. Whiteside Rae	November, 1880–March, 1883
Frederick R. Hutton	1883–1906
Calvin W. Rice	1906–date

Technical Committees

Revised to December 31, 1930. For the personnel of these committees refer to the Membership List

RESEARCH

A.S.M.E. Research Committee (Standing) (5) *
Special Committee on Lubrication (10)
Special Committees on Fluid Meters (7)
- Subcommittee on Description of Flow Meters and Water Meters—Part 2 (4)
- Subcommittee on Influence of Installation—Part 3 (8)
- Subcommittee on Revision of Part 1—Report on Fluid Meters (9)

Special Committee on Thermal Properties of Steam (15)
- Technical Subcommittees (11)

Special Committee on Strength of Gear Teeth (9)
Special Committee on Cutting of Metals (19)
- Executive Committee (3)
- Subcommittee on Physics of Cutting Metals (2)
- Subcommittee on Hard Cutting Tool Materials (9)
- Subcommittee on Properties of Materials (3)
- Subcommittee on Bibliography and Correlation (3)
- Subcommittee on Cutting Fluids (7)

Special Committee on Mechanical Springs (9)
- Executive Committee (5)
- Subcommittee on Present Status of the Art (7)
- Subcommittee on Program (10)
- Subcommittee on Spring Materials (1)
- Subcommittee on Bibliography (1)

Joint Committee on Effect of Temperature on the Properties of Metals (13)
- Subcommittee on Constitution, By-Laws, and Membership (1)
- Subcommittee on Finances (1)
- Subcommittee on Projects and Prosecution (1)
- Subcommittee on Correlation of Test Data (1)

Special Committee on Condenser Tubes (20)
- Executive Committee (6)
- Subcommittee on Questionnaire (2)
- Subcommittee on Finance (1)
- Subcommittee on Bibliography (2)

Joint Committee on Boiler Feedwater Studies (61)
- Executive Committee (21)
- Finance Committee (6)
- Subcommittee on Sedimentation With and Without Chemicals, Pressure and Gravity Filters and Deconcentrators, Continuous Blow-Down Apparatus (5)
- Subcommittee on Water Softened by Chemicals (External Treatment) (9)
- Subcommittee on Zeolite Softeners, Internal Treatment, Priming and Foaming, Electrolytic Scale Prevention (13)
- Subcommittee on Surface Condensers, Evaporators, and Deaerators (8)
- Subcommittee on Corrosion of Boilers and the Effect of Treated Water in Accelerating or Relieving These Troubles (15)
- Subcommittee on Embrittlement of Metals (12)
- Subcommittee on Municipal Water Supply in Relation to Boiler Use (12)
- Subcommittee on Standardization of Water Analysis (12)
- Subcommittee on Bibliography (8)

Special Committee on Boiler Furnace Refractories (20)
Special Committee on Elevators (9)
- Technical Program Subcommittee

Special Committee on Worm Gears (8)
Joint Committee on Welding of Pressure Vessels (49)
- Executive Committee (8)
- Subcommittee on Methods of Test (11)
- Subcommittee on Procedure of Specifications (12)
- Subcommittee on Ways and Means (1)

Special Committee on Saws and Knives (10)
Special Committee on Existing Supplies of Hardwood (9)
Special Committee on Strength of Vessels Under External Pressure (10)
Special Committee on Absorption of Radiant Heat in Boiler Furnaces (7)
Special Committee on Velocity Measurement of Fluid Flow (3)
Special Committee on Measures of Management (6)
Joint Committee on Physical Constants of Refrigerants ( )
Special Committee on Diesel Fuel Oil Specifications (35)
- Subcommittee on Physical Research (6)
- Subcommittee on Chemical Tests Research (4)
- Subcommittee on Tests and Field Data (9)

Special Committee on Airplane Vibration With Special Reference to Instruments (14)
Special Committee on Heavy Duty Anti-Friction Bearings (8)
Special Committee on Removal of Ash as Molten Slag From Powdered-Coal Furnaces (8)
Special Research Committee on Automatic Oil Pipe Line Pumping Stations (24)
Special Research Committee on Methods and Apparatus for Noise Measurement (13)
Special Research Committee on Wire Rope (11)
Representatives on Engineering Foundation (3)
Representatives on Engineering Societies Research Board (3)
Representatives on National Research Council (3)
Representatives on the Following Research Committees Sponsored by Other Organizations (6)
- Corrosion Committee (American Society of Refrigerating Engineers)
- Fatigue Phenomena of Metals (American Society for Testing Materials)
- Highway Research (Advisory Board of National Research Council)
- National Committee on Wood Utilization (Department of Commerce, Bureau of Standards)
- Non-Ferrous Metals and Alloys (Advisory to the Bureau of Standards Committee)
- Properties of Refractory Materials (Advisory to the Bureau of Standards Committee)

Approved Research Publications of the A.S.M.E.

Bibliography on Riveted Joints
Report on Fluid Meters—Their Theory and Application, Part 1 (Third Edition)
Bibliography on Mechanical Springs
Bibliography on Effect of Temperature on Properties of Metals
Bibliography on Woods of the World—Exclusive of the Temperate Region of North America and with Emphasis on Tropical Woods
Bibliography on Cutting of Metals
Research Reports and Papers, 1929 and 1930

STANDARDS

A.S.M.E. Standardization Committee (Standing) (5)
Sectional Committee on Shafting (17)
- Subcommittee on Shafting Dimensions (4)
- Subcommittee on Stock Key Sizes (5)
- Subcommittee on Code for Design of Transmission Shafting (7)
- Subcommittee on Taper Keys (3)
- Subcommittee on Woodruff Keys (15)

Allowances and Tolerances for Cylindrical Parts and Limit Gages (32)
Sectional Committee on Ball and Roller Bearings (16)
- Subcommittee on Annular Ball Bearings (7)
- Subcommittee on Annular Ball Bearings (Light, Medium, and Heavy Series) (3)

Sectional Committee on Gears (35)
- Executive Committee (3)
- Subcommittee No. 1 on Program (3)
- Subcommittee No. 2 on Editing Reports (3)
- Subcommittee No. 3 on Nomenclature (6)

* Note.—The figures in parentheses indicate the number of men serving on each committee.

Subcommittee No. 4 on Tooth Form (Spur Gear) (4)
Subcommittee No. 5 on Helical Gears (10)
Subcommittee No. 6 on Worm Gears (6)
Subcommittee No. 7 on Bevel Gears (5)
Subcommittee No. 8 on Materials (6)
Subcommittee No. 9 on Inspection (3)
Subcommittee No. 10 on Horse Power Rating (4)
Sectional Committee on Pipe Flanges and Fittings (56)
Subcommittee No. 1 on Cast Iron Flanges and Flanged Fittings (35)
Subgroup on Cast Iron Flanges for Pressures Under 100 Lb. (8)
Subgroup on Ammonia Fittings (7)
Subcommittee No. 2 on Screwed Fittings (27)
Working Committee (5)
Subcommittee No. 3 on Steel Flanges and Flanged Fittings (22)
Working Committee (10)
Subgroup on Flange Standards for 1350 Lb. Steam Pressure (4)
Subgroup on Flange Standards for Higher Than 1500 Lb. Steam Pressure (3)
Subgroup on Bolting of Flanges (5)
Subgroup on Steel Companion Flanges (6)
Subcommittee No. 4 on Materials and Stresses (7)
Subcommittee No. 5 on Face-to-Face Dimensions of Ferrous Flanged Valves (14)
Subcommittee No. 6 on Malleable Iron or Steel Brass Seat Unions (25)
Manufacturers' Subgroup (13)
Subgroup on Tolerances and Marking (7)
Subgroup on Tests and Material Requirements (3)
Subcommittee No. 7 on Rating of Pipe Fittings (9)
Subcommittee No. 8 on Marking of Pipe Fittings (7)
Sectional Committee on Bolt, Nut, and Rivet Proportions (56)
Subcommittee No. 1 on Large and Small Rivets (10)
Subcommittee No. 2 on Wrench Head Bolts and Nuts (25)
Subgroup on Nomenclature (5)
Subgroup on Large Nuts for Piping Industry (7)
Subgroup on Stud Bolts (3)
Subgroup on Wrench Openings (3)
Subgroup on Reduction of Thickness of Jam Nuts ( )
Subcommittee No. 3 on Slotted Head Proportions (10)
Subcommittee No. 4 on Track Bolts and Nuts (9)
Subcommittee No. 5 on Round Unslotted Head Bolts (Carriage Bolts) (7)
Subcommittee No. 6 on Plow Bolts (5)
Subcommittee No. 7 on Body Dimensions and Material (11)
Subcommittee No. 8 on Nomenclature (10)
Subcommittee No. 9 on Socket Head Cap and Set Screws (10)
Sectional Committee on Scheme for Identification of Piping Systems (32)
Executive Committee (5)
Subcommittee on Identification by Colors (6)
Subcommittee on Classification (4)
Subcommittee on Identification Markings Other Than Color (5)
Subcommittee on Editing (8)
Sectional Committee on Small Tools and Machine Tool Elements (17)
Executive Committee (5)
Technical Committee No. 1 on T-Slots (13)
Technical Committee No. 2 on Tool Holder Shanks and Tool Post Openings (15)
Technical Committee No. 3 on Machine Tapers (21)
Subgroup on Taper Series (8)
Subgroup on Standard Dimensions (3)
Subgroup on Detailed Dimensions, Tolerances and Gages (10)
Technical Committee No. 4 on Spindle Noses and Collets for Machine Tools (27)
Subgroup on Milling Machines, Small and Medium (3)
Subgroup on Large Milling Machines (8)
Subgroup on Grinding Machine Spindles (7)
Subgroup on Drilling Machines and Horizontal Boring Machines (7)
Subgroup on Cutting Off Machines (3)
Subgroup on Turning Machines, Including Automatic Screw Machines, Lathes, Automatic Lathes, Turret Lathes, and Automatic Chucking Machines (14)
Subgroup on Cutting and Hobbing Machines (6)
Subgroup on Correlation of Counter Proposals for Spindle Noses (5)
Technical Committee No. 5 on Milling Cutters (23)
Subgroup on Profile Cutters (4)
Subgroup on Keyways (4)
Subgroup on Nomenclature (4)
Subgroup on Limits (4)
Subgroup on Formed Cutters (4)
Subgroup on Hobs (4)
Subgroup on Inserted Tooth Cutters (4)
Technical Committee No. 6 on Designations and Working Ranges of Machine Tools (23)
Technical Committee No. 7 on Twist Drill Sizes (9)
Subgroup on Lengths and Diameters of Drills (3)
Technical Committee No. 8 on Drill Bushings (9)
Subgroup on Liner Outer Diameters and Tolerances (3)
Technical Committee No. 9 on Punch and Die Holders (12)
Subgroup on Sizes, Styles, and Materials (6)
Technical Committee No. 10 on Circular Forming Tools and Holders ( )
Technical Committee No. 11 on Chucks and Chuck Jaws (9)
Subgroup on Master Chuck Jaws (5)
Subgroup on Adapters for Air Cylinders (4)
Technical Committee No. 12 on Cut and Ground Thread Taps (7)
Technical Committee No. 13 on Splines and Splined Shafts (12)
Subgroup on Machine Tools (1)
Subgroup on Automotive Splines (1)
Technical Committee No. 14 on Electric Welding Dies and Electrode Holders (9)
Technical Committee No. 15 on Standardization of Milling Machine Tables (5)
Subgroup on Tee Slot Spacing (1)
Sectional Committee on Scientific and Engineering Symbols and Abbreviations (33)
Executive Committee (7)
Subcommittee No. 1 on Symbols for Mechanics, Structural Engineering and Testing Materials (12)
Subcommittee No. 2 on Symbols for Hydraulics (13)
Subgroup on Theoretical Hydraulics (3)
Subgroup on Hydrology (2)
Subgroup on Water Power (2)
Subgroup on Pumps and Pumping Equipment (2)
Subgroup on Sanitary Engineering and Water Piping (2)
Subgroup on Irrigation (1)
Subgroup on Turbines (2)
Subcommittee No. 3 on Symbols for Heat and Thermodynamics (30)
Subcommittee No. 4 on Photometry and Illumination (15)
Subcommittee No. 5 on Aeronautical Symbols (11)
Subcommittee No. 6 on Mathematical Symbols (14)
Subcommittee No. 7 on Electrotechnical Symbols, Including Radio (15)
Subgroup on Letter Symbols (4)
Subgroup on Symbols for Electric Power, Including Interior Wiring (7)
Subgroup on Graphical Symbols for Radio (7)
Subgroup on Supply Material ( )
Subgroup on Traction, Including Railway Signaling (4)
Subgroup on Graphical Symbols for Telephone and Telegraph Use (5)
Subcommittee No. 8 on Navigational and Topographical Symbols (3)
Subcommittee No. 9 on Abbreviations for Engineering and Scientific Terms (5)
Sectional Committee on Plain and Lock Washers (27)
Subcommittee No. 1 on Plain Washers (9)
Subcommittee No. 2 on Lock Washers (21)
Sectional Committee on Machine Pins (14)
Subcommittee No. 1 on Straight, Taper, and Dowel Pins ( )
Subcommittee No. 2 on Split Pins ( )
Sectional Committee on Code for Pressure Piping (68)
Subcommittee No. 1 on Plan and Scope (6)
Subcommittee No. 2 on Power Piping (23)
Subgroup on Code for District Heating Piping (8)
Subcommittee No. 3 on Hydraulic Piping (8)
Subgroup on Penstock Work (1)
Subgroup on Hydraulic High Pressure Piping (1)
Subgroup on Water Works Piping (1)
Subcommittee No. 4 on Gas and Air Piping (18)
Subcommittee No. 5 on Refrigerating Piping (9)
Subcommittee No. 6 on Oil Piping (7)
Subcommittee No. 7 on Piping Materials and Identification (13)
Subcommittee No. 8 on Fabrication Details (18)
Subgroup on Hangers, Supports, and Anchors (1)
Subgroup on Joints Other Than Welded (1)
Subgroup on Pipe Bends (1)
Subgroup on Power Piping (1)
Subgroup on Welding (1)

TREASURERS

LYCURGUS B. MOORE . . . . . April, 1880–December, 1881
CHAS. W. COPELAND. . . . . December, 1881–November, 1884
WILLIAM H. WILEY 1884–1925
ERIK OBERG 1925–date

SECRETARIES

SAM S. WEBBER, JR. . . . Secretary, Organization Meeting, 1880
LYCURGUS B. MOORE . . . Acting Secretary, April–November, 1880
THOS. WHITESIDE RAE. . . . . November, 1880–March, 1883
FREDERICK R. HUTTON 1883–1906
CALVIN W. RICE 1906–date

Technical Committees

Revised to December 31, 1930. For the personnel of these committees refer to the Membership List

RESEARCH

A.S.M.E. Research Committee (Standing) (5) *
SPECIAL COMMITTEE ON LUBRICATION (10)
SPECIAL COMMITTEES ON FLUID METERS (7)
- Subcommittee on Description of Flow Meters and Water Meters—Part 2 (4)
- Subcommittee on Influence of Installation—Part 3 (8)
- Subcommittee on Revision of Part 1—Report on Fluid Meters (9)

SPECIAL COMMITTEE ON THERMAL PROPERTIES OF STEAM (15)
- Technical Subcommittees (11)

SPECIAL COMMITTEE ON STRENGTH OF GEAR TEETH (9)
SPECIAL COMMITTEE ON CUTTING OF METALS (19)
- Executive Committee (3)
- Subcommittee on Physics of Cutting Metals (2)
- Subcommittee on Hard Cutting Tool Materials (9)
- Subcommittee on Properties of Materials (3)
- Subcommittee on Bibliography and Correlation (3)
- Subcommittee on Cutting Fluids (7)

SPECIAL COMMITTEE ON MECHANICAL SPRINGS (9)
- Executive Committee (5)
- Subcommittee on Present Status of the Art (7)
- Subcommittee on Program (10)
- Subcommittee on Spring Materials (1)
- Subcommittee on Bibliography (1)

JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON THE PROPERTIES OF METALS (13)
- Subcommittee on Constitution, By-Laws, and Membership (1)
- Subcommittee on Finances (1)
- Subcommittee on Projects and Prosecution (1)
- Subcommittee on Correlation of Test Data (1)

SPECIAL COMMITTEE ON CONDENSER TUBES (20)
- Executive Committee (6)
- Subcommittee on Questionnaire (2)
- Subcommittee on Finance (1)
- Subcommittee on Bibliography (2)

JOINT COMMITTEE ON BOILER FEEDWATER STUDIES (61)
- Executive Committee (21)
- Finance Committee (6)
- Subcommittee on Sedimentation With and Without Chemicals, Pressure and Gravity Filters and Deconcentrators, Continuous Blow-Down Apparatus (5)
- Subcommittee on Water Softened by Chemicals (External Treatment) (9)
- Subcommittee on Zeolite Softeners, Internal Treatment, Priming and Foaming, Electrolytic Scale Prevention (13)
- Subcommittee on Surface Condensers, Evaporators, and Deaerators (8)
- Subcommittee on Corrosion of Boilers and the Effect of Treated Water in Accelerating or Relieving These Troubles (15)
- Subcommittee on Embrittlement of Metals (12)
- Subcommittee on Municipal Water Supply in Relation to Boiler Use (12)
- Subcommittee on Standardization of Water Analysis (12)
- Subcommittee on Bibliography (8)

SPECIAL COMMITTEE ON BOILER FURNACE REFRACTORIES (20)
SPECIAL COMMITTEE ON ELEVATORS (9)
- Technical Program Subcommittee

SPECIAL COMMITTEE ON WORM GEARS (8)
JOINT COMMITTEE ON WELDING OF PRESSURE VESSELS (49)
- Executive Committee (8)
- Subcommittee on Methods of Test (11)
- Subcommittee on Procedure of Specifications (12)
- Subcommittee on Ways and Means (1)

SPECIAL COMMITTEE ON SAWS AND KNIVES (10)
SPECIAL COMMITTEE ON EXISTING SUPPLIES OF HARDWOOD (9)
SPECIAL COMMITTEE ON STRENGTH OF VESSELS UNDER EXTERNAL PRESSURE (10)
SPECIAL COMMITTEE ON ABSORPTION OF RADIANT HEAT IN BOILER FURNACES (7)
SPECIAL COMMITTEE ON VELOCITY MEASUREMENT OF FLUID FLOW (3)
SPECIAL COMMITTEE ON MEASURES OF MANAGEMENT (6)
JOINT COMMITTEE ON PHYSICAL CONSTANTS OF REFRIGERANTS ( )
SPECIAL COMMITTEE ON DIESEL FUEL OIL SPECIFICATIONS (35)
- Subcommittee on Physical Research (6)
- Subcommittee on Chemical Tests Research (4)
- Subcommittee on Tests and Field Data (9)

SPECIAL COMMITTEE ON AIRPLANE VIBRATION WITH SPECIAL REFERENCE TO INSTRUMENTS (14)
SPECIAL COMMITTEE ON HEAVY DUTY ANTI-FRICTION BEARINGS (8)
SPECIAL COMMITTEE ON REMOVAL OF ASH AS MOLTEN SLAG FROM POWDERED-COAL FURNACES (8)
SPECIAL RESEARCH COMMITTEE ON AUTOMATIC OIL PIPE LINE PUMPING STATIONS (24)
SPECIAL RESEARCH COMMITTEE ON METHODS AND APPARATUS FOR NOISE MEASUREMENT (13)
SPECIAL RESEARCH COMMITTEE ON WIRE ROPE (11)
REPRESENTATIVES ON ENGINEERING FOUNDATION (3)
REPRESENTATIVES ON ENGINEERING SOCIETIES RESEARCH BOARD (3)
REPRESENTATIVES ON NATIONAL RESEARCH COUNCIL (3)
REPRESENTATIVES ON THE FOLLOWING RESEARCH COMMITTEES SPONSORED BY OTHER ORGANIZATIONS (6)
- Corrosion Committee (American Society of Refrigerating Engineers)
- Fatigue Phenomena of Metals (American Society for Testing Materials)
- Highway Research (Advisory Board of National Research Council)
- National Committee on Wood Utilization (Department of Commerce, Bureau of Standards)
- Non-Ferrous Metals and Alloys (Advisory to the Bureau of Standards Committee)
- Properties of Refractory Materials (Advisory to the Bureau of Standards Committee)

APPROVED RESEARCH PUBLICATIONS OF THE A.S.M.E.

Bibliography on Riveted Joints
Report on Fluid Meters—Their Theory and Application, Part 1 (Third Edition)
Bibliography on Mechanical Springs
Bibliography on Effect of Temperature on Properties of Metals
Bibliography on Woods of the World—Exclusive of the Temperate Region of North America and with Emphasis on Tropical Woods
Bibliography on Cutting of Metals
Research Reports and Papers, 1929 and 1930

STANDARDS

A.S.M.E. Standardization Committee (Standing) (5)
SECTIONAL COMMITTEE ON SHAFTING (17)
- Subcommittee on Shafting Dimensions (4)
- Subcommittee on Stock Key Sizes (5)
- Subcommittee on Code for Design of Transmission Shafting (7)
- Subcommittee on Taper Keys (3)
- Subcommittee on Woodruff Keys (15)

ALLOWANCES AND TOLERANCES FOR CYLINDRICAL PARTS AND LIMIT GAGES (32)
SECTIONAL COMMITTEE ON BALL AND ROLLER BEARINGS (16)
- Subcommittee on Annular Ball Bearings (7)
- Subcommittee on Annular Ball Bearings (Light, Medium, and Heavy Series) (3)

SECTIONAL COMMITTEE ON GEARS (35)
- Executive Committee (3)
- Subcommittee No. 1 on Program (3)
- Subcommittee No. 2 on Editing Reports (3)
- Subcommittee No. 3 on Nomenclature (6)

* NOTE.—The figures in parentheses indicate the number of men serving on each committee.

Subcommittee No. 4 on Tooth Form (Spur Gear) (4)
Subcommittee No. 5 on Helical Gears (10)
Subcommittee No. 6 on Worm Gears (6)
Subcommittee No. 7 on Bevel Gears (5)
Subcommittee No. 8 on Materials (6)
Subcommittee No. 9 on Inspection (3)
Subcommittee No. 10 on Horse Power Rating (4)
Sectional Committee on Pipe Flanges and Fittings (56)
Subcommittee No. 1 on Cast Iron Flanges and Flanged Fittings (35)
Subgroup on Cast Iron Flanges for Pressures Under 100 Lb. (8)
Subgroup on Ammonia Fittings (7)
Subcommittee No. 2 on Screwed Fittings (27)
Working Committee (5)
Subcommittee No. 3 on Steel Flanges and Flanged Fittings (22)
Working Committee (10)
Subgroup on Flange Standards for 1350 Lb. Steam Pressure (4)
Subgroup on Flange Standards for Higher Than 1500 Lb. Steam Pressure (3)
Subgroup on Bolting of Flanges (5)
Subgroup on Steel Companion Flanges (6)
Subcommittee No. 4 on Materials and Stresses (7)
Subcommittee No. 5 on Face-to-Face Dimensions of Ferrous Flanged Valves (14)
Subcommittee No. 6 on Malleable Iron or Steel Brass Seat Unions (25)
Manufacturers' Subgroup (13)
Subgroup on Tolerances and Marking (7)
Subgroup on Tests and Material Requirements (3)
Subcommittee No. 7 on Rating of Pipe Fittings (9)
Subcommittee No. 8 on Marking of Pipe Fittings (7)
Sectional Committee on Bolt, Nut, and Rivet Proportions (56)
Subcommittee No. 1 on Large and Small Rivets (10)
Subcommittee No. 2 on Wrench Head Bolts and Nuts (25)
Subgroup on Nomenclature (5)
Subgroup on Large Nuts for Piping Industry (7)
Subgroup on Stud Bolts (3)
Subgroup on Wrench Openings (3)
Subgroup on Reduction of Thickness of Jam Nuts ( )
Subcommittee No. 3 on Slotted Head Proportions (10)
Subcommittee No. 4 on Track Bolts and Nuts (9)
Subcommittee No. 5 on Round Unslotted Head Bolts (Carriage Bolts) (7)
Subcommittee No. 6 on Plow Bolts (5)
Subcommittee No. 7 on Body Dimensions and Material (11)
Subcommittee No. 8 on Nomenclature (10)
Subcommittee No. 9 on Socket Head Cap and Set Screws (10)
Sectional Committee on Scheme for Identification of Piping Systems (32)
Executive Committee (5)
Subcommittee on Identification by Colors (6)
Subcommittee on Classification (4)
Subcommittee on Identification Markings Other Than Color (5)
Subcommittee on Editing (8)
Sectional Committee on Small Tools and Machine Tool Elements (17)
Executive Committee (5)
Technical Committee No. 1 on T-Slots (13)
Technical Committee No. 2 on Tool Holder Shanks and Tool Post Openings (15)
Technical Committee No. 3 on Machine Tapers (21)
Subgroup on Taper Series (8)
Subgroup on Standard Dimensions (3)
Subgroup on Detailed Dimensions, Tolerances and Gages (10)
Technical Committee No. 4 on Spindle Noses and Collets for Machine Tools (27)
Subgroup on Milling Machines, Small and Medium (3)
Subgroup on Large Milling Machines (8)
Subgroup on Grinding Machine Spindles (7)
Subgroup on Drilling Machines and Horizontal Boring Machines (7)
Subgroup on Cutting Off Machines (3)
Subgroup on Turning Machines, Including Automatic Screw Machines, Lathes, Automatic Lathes, Turret Lathes, and Automatic Chucking Machines (14)
Subgroup on Cutting and Hobbing Machines (6)
Subgroup on Correlation of Counter Proposals for Spindle Noses (5)
Technical Committee No. 5 on Milling Cutters (23)
Subgroup on Profile Cutters (4)
Subgroup on Keyways (4)
Subgroup on Nomenclature (4)
Subgroup on Limits (4)
Subgroup on Formed Cutters (4)
Subgroup on Hobs (4)
Subgroup on Inserted Tooth Cutters (4)
Technical Committee No. 6 on Designations and Working Ranges of Machine Tools (23)
Technical Committee No. 7 on Twist Drill Sizes (9)
Subgroup on Lengths and Diameters of Drills (3)
Technical Committee No. 8 on Drill Bushings (9)
Subgroup on Liner Outer Diameters and Tolerances (3)
Technical Committee No. 9 on Punch and Die Holders (12)
Subgroup on Sizes, Styles, and Materials (6)
Technical Committee No. 10 on Circular Forming Tools and Holders ( )
Technical Committee No. 11 on Chucks and Chuck Jaws (9)
Subgroup on Master Chuck Jaws (5)
Subgroup on Adapters for Air Cylinders (4)
Technical Committee No. 12 on Cut and Ground Thread Taps (7)
Technical Committee No. 13 on Splines and Splined Shafts (12)
Subgroup on Machine Tools (1)
Subgroup on Automotive Splines (1)
Technical Committee No. 14 on Electric Welding Dies and Electrode Holders (9)
Technical Committee No. 15 on Standardization of Milling Machine Tables (5)
Subgroup on Tee Slot Spacing (1)
Sectional Committee on Scientific and Engineering Symbols and Abbreviations (33)
Executive Committee (7)
Subcommittee No. 1 on Symbols for Mechanics, Structural Engineering and Testing Materials (12)
Subcommittee No. 2 on Symbols for Hydraulics (13)
Subgroup on Theoretical Hydraulics (3)
Subgroup on Hydrology (2)
Subgroup on Water Power (2)
Subgroup on Pumps and Pumping Equipment (2)
Subgroup on Sanitary Engineering and Water Piping (2)
Subgroup on Irrigation (1)
Subgroup on Turbines (2)
Subcommittee No. 3 on Symbols for Heat and Thermodynamics (30)
Subcommittee No. 4 on Photometry and Illumination (15)
Subcommittee No. 5 on Aeronautical Symbols (11)
Subcommittee No. 6 on Mathematical Symbols (14)
Subcommittee No. 7 on Electrotechnical Symbols, Including Radio (15)
Subgroup on Letter Symbols (4)
Subgroup on Symbols for Electric Power, Including Interior Wiring (7)
Subgroup on Graphical Symbols for Radio (7)
Subgroup on Supply Material ( )
Subgroup on Traction, Including Railway Signaling (4)
Subgroup on Graphical Symbols for Telephone and Telegraph Use (5)
Subcommittee No. 8 on Navigational and Topographical Symbols (3)
Subcommittee No. 9 on Abbreviations for Engineering and Scientific Terms (5)
Sectional Committee on Plain and Lock Washers (27)
Subcommittee No. 1 on Plain Washers (9)
Subcommittee No. 2 on Lock Washers (21)
Sectional Committee on Machine Pins (14)
Subcommittee No. 1 on Straight, Taper, and Dowel Pins ( )
Subcommittee No. 2 on Split Pins ( )
Sectional Committee on Code for Pressure Piping (68)
Subcommittee No. 1 on Plan and Scope (6)
Subcommittee No. 2 on Power Piping (23)
Subgroup on Code for District Heating Piping (8)
Subcommittee No. 3 on Hydraulic Piping (8)
Subgroup on Penstock Work (1)
Subgroup on Hydraulic High Pressure Piping (1)
Subgroup on Water Works Piping (1)
Subcommittee No. 4 on Gas and Air Piping (18)
Subcommittee No. 5 on Refrigerating Piping (9)
Subcommittee No. 6 on Oil Piping (7)
Subcommittee No. 7 on Piping Materials and Identification (13)
Subcommittee No. 8 on Fabrication Details (18)
Subgroup on Hangers, Supports, and Anchors (1)
Subgroup on Joints Other Than Welded (1)
Subgroup on Pipe Bends (1)
Subgroup on Power Piping (1)
Subgroup on Welding (1)

SECTIONAL COMMITTEE ON STANDARDS FOR DRAWINGS AND DRAFTING ROOM PRACTICE (50)
- Subcommittee No. 1 on Specifications for Paper and Cloth (14)
  - Subgroup on Materials Specification (3)
- Subcommittee No. 2 on Method of Indicating Dimensions (10)
- Subcommittee No. 3 on Lettering (9)
  - Subgroup on Questionnaire (2)
- Subcommittee No. 4 on Layout (11)
- Subcommittee No. 5 on Line Work (10)
- Subcommittee No. 6 on Graphical Symbols for Drawings (10)
- Subcommittee on Editing (6)

SECTIONAL COMMITTEE ON STANDARDS FOR GRAPHIC PRESENTATION (42)
- Subcommittee No. 1 on Plan and Scope (9)
- Subcommittee No. 2 on Terminology (7)
- Subcommittee No. 3 on Time Series Charts (7)
- Subcommittee No. 4 on Non-Time Series Charts (8)
- Subcommittee No. 5 on Survey of Current Practice (8)
- Subcommittee No. 6 on Engineering and Scientific Graphs (9)

SECTIONAL COMMITTEE ON TRANSMISSION CHAINS AND SPROCKETS (17)
- Subcommittee on Roller Chain Standardization (7)
- Subcommittee on Silent Chain Standardization (7)

SECTIONAL COMMITTEE ON WIRE AND SHEET METAL GAGING SYSTEMS (27)
- Technical Committee on Flat Stocks (8)
- Technical Committee on Wires and Rods (9)
- Technical Committee on Tubing, Piping, Conduit, and Casing (4)

SECTIONAL COMMITTEE ON ELECTRIC MOTOR FRAME DIMENSIONS (32)
- Working Committee (7)

SECTIONAL COMMITTEE ON PIPE THREADS (45)
- Subcommittee No. 1 on Editing and Gaging (14)
- Subcommittee No. 2 on Taper Pipe Threads (10)
- Subcommittee No. 3 on Straight Pipe Threads (11)
  - Working Committee (2)
- Subcommittee No. 4 on Plumbers' Threads, Etc. (13)
  - Subgroup on Thread Pitch Diameters and Characteristics (1)
  - Subgroup to Study Existing Thread Dimensions of Cocks and Stops (3)
  - Subgroup on Fine Threads for Tubing Larger Than 2 Inches (1)
- Subcommittee No. 5 on Screw Threads for Rigid Electrical Conduit (6)
- Subcommittee No. 6 on Special Threads for Thin Tubes (8)

SECTIONAL COMMITTEE ON WROUGHT IRON AND WROUGHT STEEL PIPE AND TUBING (39)
- Subcommittee No. 1 on Plan, Scope, and Editing (5)
- Subcommittee No. 2 on Pipe and Tubing for Low-Temperature Service (16)
- Subcommittee No. 3 on Pipe and Tubing for High-Temperature Service (17)
  - Subgroup on Basic Formulas and Stresses (9)
- Subcommittee No. 4 on Materials (17)

SECTIONAL COMMITTEE ON SPEEDS OF MACHINERY (32)
- Subcommittee No. 1 on Plan and Scope (7)
- Subcommittee No. 2 on Questionnaire and Canvas to Industry (7)

SECTIONAL COMMITTEE ON SCREW THREADS FOR FIRE HOSE COUPLINGS ( )

SECTIONAL COMMITTEE ON SCREW THREADS FOR HOSE COUPLINGS (26)
- Special Subcommittee to Draft Recommended Specifications (3)
- Subcommittee on Basic Thread Dimensions (3)

SECTIONAL COMMITTEE ON PLUMBING EQUIPMENT (32)
- Subcommittee No. 1 on Plumbing Code (6)
- Subcommittee No. 2 on Staple Vitreous China Plumbing Fixtures (11)
- Subcommittee No. 3 on Staple Porcelain (All Clay) Plumbing Fixtures (19)
- Subcommittee No. 4 on Enameled Sanitary Ware ( )
- Subcommittee No. 5 on Traps (24)
  - Subgroup on Brass Lavatories and Sink Traps (8)
  - Subgroup on Brass Traps (5)
  - Subgroup on Cast Iron Traps (18)
  - Subgroup on Lead Traps (1)
  - Subgroup on Vitreous China Traps (1)
  - Subgroup on Interceptors, Catch Basins, and Miscellaneous Traps (1)
- Subcommittee No. 6 on Standardization of Brass Plumbing Products (13)
  - Subgroup on Compression Cocks, Washer Screws, Faucets, and Tail Piece Parts (2)
  - Subgroup on Flushing Tank Mechanism and Flush Valves, Supply Pipes and Connections, and Escutcheons (2)
  - Subgroup on Fixture Connections and Fixture Valves, Waste Holes, Plugs, and Connections; Overflows (3)
  - Subgroup on Valves (2)
  - Subgroup on Shower Heads, Diameter Connections, and Sizes (3)
  - Subgroup on Water Works Brass (1)
  - Subgroup on Nomenclature (7)
- Subcommittee No. 7 on Copper Water Tube Fittings (6)
- Subcommittee No. 8 on Cast Iron Soil Pipe and Fittings (9)

SECTIONAL COMMITTEE ON STANDARDIZATION AND UNIFICATION OF SCREW THREADS (38)
- Subcommittee No. 1 on Scope, Arrangement, and Editing of American National Standards (8)
- Subcommittee No. 2 on Terminology and Thread Specifications, Except Gages (13)
  - Subgroup on Minor Diameter of Nuts (4)
- Subcommittee No. 3 on Special Threads and Twelve Pitch Series, Except Gages (11)
  - Subgroup on Eight Pitch Thread Series (1)
  - Subgroup on Screw Thread Tolerances for Track Bolts and Nuts (1)
- Subcommittee No. 4 on Acme and Other Similar Threads, Except Gages (7)
- Subcommittee No. 5 on Screw Thread Gages and Inspection (9)
  - Subgroup on Drafting Report (3)
  - Subgroup on Tolerances for Different Classes of Gages ( )
- Subcommittee No. 6 on Lag Screws (2)
- Subcommittee No. 7 on Survey of Present Practice (3)

SECTIONAL COMMITTEE ON ROLLED THREADS FOR SCREW SHELLS OF ELECTRIC SOCKETS AND LAMP BASES (18)
- Subcommittee No. 1 (9)

SECTIONAL COMMITTEE ON STOCK SIZES, SHAPES, AND LENGTHS FOR HOT AND COLD FINISHED IRON AND STEEL BARS (18)
- Subcommittee No. 1 on Hot Rolled Steel (6)
- Subcommittee No. 2 on Cold Finished Steels (4)
- Subcommittee No. 3 on Hot Rolled Iron (1)

SECTIONAL COMMITTEE ON PRESSURE AND VACUUM GAGES (35)

REPRESENTATIVES ON AMERICAN STANDARDS ASSOCIATION (3)

REPRESENTATIVES ON THE FOLLOWING STANDARDIZATION COMMITTEES SPONSORED BY OTHER ORGANIZATIONS (31)
- Building Code Committee (Advisory Committee of Department of Commerce)
- Classification of Coal (American Society for Testing Materials)
- Drainage of Coal Mines (American Mining Congress)
- Electrical Definitions (American Institute of Electrical Engineers)
- Electric Welding (American Institute of Electrical Engineers and the National Electrical Manufacturers Association)
- Fire Test Building Construction and Materials (American Society for Testing Materials and Bureau of Standards, Fire Protection Group)
- Manhole Frames and Covers (American Society of Civil Engineers and Telephone Group)
- Methods for Testing Wood (American Society for Testing Materials and the Forest Service)
- Methods of Rating of Rivers (U. S. Geological Survey)
- Methods of Testing Petroleum Products and Lubricants (American Society for Testing Materials)
- Miscellaneous Outside Coal-Handling Equipment (American Mining Congress)
- National Fire Waste Council
- Petroleum Specifications (Advisory Board of Bureau of Mines)
- Rotating Electrical Machinery (American Institute of Electrical Engineers and the National Electrical Manufacturers Association)
- Specifications for and Recommended Practice in the Use of Wire Rope for Mines (American Mining Congress)
- Specification for Fuel Oils (American Society for Testing Materials)
- Specifications for Cast-Iron Pipe (American Gas Association, American Society for Testing Materials, American Water Works Association, and New England Water Works Association)
- Specifications for Materials for Use in Manufacture of Special Trackwork (American Electric Railway Association)
- Specifications for Tool Steel (Subcommittee No. XIV of A.S.T.M. Committee A-1 on Steel)
- Steel Railway and Movable Railway Bridges (Special American Standards Association Committee)

APPROVED STANDARDS PUBLISHED BY THE A.S.M.E.

Cold Finished Shafting, Standard Diameters and Lengths
Square and Flat Stock Keys, Standard Widths and Heights
Plain Taper Stock Keys, Square and Flat
Gib Head Taper Stock Keys, Square and Flat

Code for Design of Transmission Shafting
Tolerances, Allowances, and Gages for Metal Fits
Spur Gear Tooth Form, 14½ Degree Composite System, 20 Degrees Stub Involute System
American Standard Screw Threads for Bolts, Machine Screws, Nuts, and Commercially Tapped Holes
Cast Iron Pipe Flanges and Flanged Fittings; All Sizes for Maximum Working Saturated Steam Pressure of 125 Lb. per Sq. In. (Gage); Sizes 12 Inches and Smaller for Maximum Non-Shock Working Hydraulic Pressure of 175 Lb. per Sq. in. (Gage) at or Near the Ordinary Range of Air Temperatures
Cast Iron Pipe Flanges and Flanged Fittings; All Sizes for Maximum Working Saturated Steam Pressure of 250 Lb. per Sq. In. (Gage); Sizes 10 Inches and Smaller for Maximum Non-Shock Working Hydraulic Pressure of 400 Lb. per Sq. In. (Gage) at or Near the Ordinary Range of Air Temperatures
Cast Iron Screwed Fittings, for Maximum Working Saturated Steam Pressure of 125 and 250 Lb. per Sq. In. (Gage)
Malleable Iron Screwed Fittings, for Maximum Working Saturated Steam Pressure of 150 Lb. per Sq. In. (Gage)
Cast Iron Long Turn Sprinkler Fittings (Screwed and Flanged) for Maximum Hydraulic Working Pressures of 150 and 250 Lb. per Sq. In. (Gage)
Steel Pipe Flanges and Flanged Fittings for Maximum Working Steam Pressures of 250, 400, 600, 900, and 1350 Lb. per Sq. In. (Gage) at a Temperature of 750 Deg. Fahr.
Small Rivets, 7/16 Inch Nominal Diameter and Under
Tinners', Coopers', and Belt Rivets
Wrench Head Bolts and Nuts and Wrench Openings
Round Unslotted Head Bolts (Carriage, Step, and Machine Bolts)
Slotted Head Proportions; Machine Screws, Cap Screws, and Wood Screws
Plow Bolts
Track Bolts
Scheme for Identification of Piping Systems
T-Slots, Their Bolts, Nuts, Tongues, and Cutters
Tool Holder Shanks and Tool Post Openings
Taps—Cut and Ground Thread
Milling Cutters—Nomenclature, Diameters, Thickness, and Other Important Dimensions
Symbols for Hydraulics
Aeronautical Symbols
Mathematical Symbols
Symbols for Photometry and Illumination
Fire Hose Coupling Screw Thread for All Connections Having Nominal Inside Diameters of 2½, 3, 3½, and 4½ Inches

SAFETY

A.S.M.E. Safety Committee (Standing) (5)
Sectional Committee on Safety Code for Mechanical Power Transmission Apparatus (28)
- Subcommittee No. 1 for Detail Classification of Belts (5)
- Subcommittee No. 2 for Modification of Rule 223 for Cone Pulley Belts (3)
- Subcommittee No. 3 on Mechanical Power Control (13)
- Subcommittee No. 4 on Use of A.S.A. Code Versus State Codes (5)
- Subcommittee No. 5 on Statistics on Place of Occurrence of Accidents (8)

Sectional Committee on Safety Code for Elevators (38)
- Subcommittee on Research, Recommendations, and Interpretations (10)
- Subcommittee on Inspectors Handbook (9)
- Subcommittee on Elevator Systems Safe Against Fire (6)
- Subcommittee on Interlocks and Hoistway Enclosures (6)

Sectional Committee on Safety Code for Machinery for Compressing Air (28)
Sectional Committee on Safety Code for Conveyors and Conveying Machinery (46)
- Subcommittee No. 1 on All Types of Chain Conveyors and Elevators; Also Cable Flight Conveyors, Omitting Track Scraper Conveyors (6)
- Subcommittee No. 2 on Belt Conveyors and Belt Elevators, Including Steel Belt (11)
- Subcommittee No. 3 on Gravity Conveyors and Chutes, Live Roll Conveyors (8)
- Subcommittee No. 4 on Spiral and Track or Scraper Conveyors (9)
- Subcommittee No. 5 on Cable Conveyors (5)
- Subcommittee No. 6 on Air, Steam, or Liquid Conveyors (6)

Sectional Committee on Safety Code for Cranes, Derricks, and Hoists (63)
- Executive Committee (6)
- Subcommittee No. 1 on Overhead and Gantry Cranes (22)
- Subcommittee No. 2 on Locomotive and Tractor Cranes (17)
- Subcommittee No. 3 on Derrick and Hoists (17)
- Subcommittee No. 4 on Miscellaneous Equipment for Cranes and Hoists (21)
- Subcommittee No. 5 on Jacks (8)

Editing Committee (3)
Representatives on the Following Safety Code Committees Sponsored by Other Organizations (33)
- Abrasive Wheels (Grinding Wheel Manufacturers Association of the U. S. and Canada, and International Association of Industrial Accident Boards and Commissions)
- Aeronautics (Society of Automotive Engineers)
- Amusement Parks (National Association of Amusement Parks and the National Bureau of Casualty and Surety Underwriters)
- Coal Mine Ventilation (American Mining Congress and the Bureau of Mines)
- Colors for Gas Mask Canisters (National Safety Council)
- Correlating Committee
- Floor Openings, Railings, and Toe Boards (National Safety Council)
- Forging and Hot Metal Stamping (American Drop Forging Institute and the National Safety Council)
- Industrial Sanitation (U. S. Public Health Service)
- Ladders (National Safety Council)
- Laundry Machinery and Operation (Association of Governmental Officials in Industry of the United States and Canada, Laundry Owners National Association, and the National Association of Mutual Casualty Companies)
- Lighting Factories, Mills, and Other Work Places (Illuminating Engineering Society)
- Logging and Sawmill Machinery (Bureau of Standards)
- Low Voltage Electrical Hazard (Special Committee of the American Society of Safety Engineers—Engineering Section, National Safety Council)
- Machine Tools (National Bureau of Casualty and Surety Underwriters and the National Machine Tool Builders Association)
- Mechanical Refrigeration (American Society of Refrigerating Engineers)
- Metal Mine Ventilation (American Mining Congress and the Bureau of Mines)
- Paper and Pulp Mills (National Safety Council)
- Power Presses and Foot and Hand Presses (National Safety Council)
- Rubber Machinery (International Association of Industrial Accident Boards and Commissions and the National Safety Council)
- Textiles (National Safety Council)
- Underground Power Transmission and Power Equipment for Metal Mines (American Mining Congress, National Standardisation Division)
- Ventilation (American Society of Heating and Ventilating Engineers)
- Walkway Surfaces (American Institute of Architects and the National Safety Council)
- Window Washing (National Safety Council)

Approved Safety Codes Published by the A.S.M.E.

A Safety Code for Elevators, Dumbwaiters, and Escalators
Safety Code for Mechanical Power-Transmission Apparatus

POWER TEST CODES

Main Committee on Power Test Codes (Standing) (25)
Individual Committee No. 1 on General Instructions (4)
Individual Committee No. 2 on Definitions and Values (5)
Individual Committee No. 3 on Fuels (15)
Individual Committee No. 4 on Stationary Steam-Generating Units (5)
Individual Committee No. 5 on Reciprocating Steam Engines (6)
Individual Committee No. 6 on Steam Turbines (8)
Individual Committee No. 7 on Reciprocating Steam-Driven Displacement Pumps (9)
Individual Committee No. 8 on Centrifugal and Rotary Pumps (7)
Individual Committee No. 9 on Displacement Compressors and Blowers (6)
Individual Committee No. 10 on Centrifugal and Turbo-Compressors and Blowers (10)
Individual Committee No. 11 on Complete Steam Power Plants (8)
Individual Committee No. 12 on Condenser, Water-Heating and Cooling Equipment (7)
Individual Committee No. 13 on Refrigerating Systems (6)
Individual Committee No. 14 on Evaporating Apparatus (5)
Individual Committee No. 15 on Steam Locomotives (7)
Individual Committee No. 16 on Gas Producers (5)
Individual Committee No. 17 on Internal-Combustion Engines (6)
Individual Committee No. 18 on Hydraulic Power Plants and Their Equipment (13)

Individual Committee No. 19 on Instruments and Apparatus (17)
Individual Committee No. 20 on Speed-Responsive Governors (4)
Representatives on U. S. National Committee of the International Electrotechnical Commission (8)

APPROVED TEST CODES PUBLISHED BY THE A.S.M.E.

General Instructions
Definitions and Values
Liquid Fuels
Solid Fuels
Stationary Steam-Generating Units
Reciprocating Steam Engines
Steam Turbines
Reciprocating Steam-Driven Displacement Pumps
Centrifugal and Rotary Pumps
Displacement Compressors and Blowers
Condensing Apparatus
Feedwater Heaters
Atmospheric Water-Cooling Equipment
Refrigerating Systems
Evaporating Apparatus
Steam Locomotives
Gas Producers
Internal-Combustion Engines
Hydraulic Power Plants and Their Equipment
Speed-Responsive Governors
Instruments and Apparatus:
- Part 1, General Considerations
- Part 2, Pressure Measurement; Chapter 1, Barometers and Chapter 6, Tables, Multipliers and Standards for Barometers, Mercury and Water Columns and Pressure Measurements
- Part 21, Leakage Measurement; Chapter 1, Condenser Leakage Tests

BOILER CODE

Main Committee on Boiler Code (23)
- Executive Committee (7)
- Subcommittee on Boilers of Locomotives (4)
- Subcommittee on Care of Steam Boilers in Service (11)
- Subcommittee on Heating Boilers (6)
- Subcommittee on Material Specifications (4)
  - Conferring Committee of the American Society for Testing Materials (3)
  - Conferring Committee of the Association of American Steel Manufacturers (3)
- Subcommittee on Miniature Boilers (7)
- Subcommittee on Rules for Inspection (8)
- Subcommittee on Unfired Pressure Vessels (4)
- Subcommittee on Welding (12)
  - Conferring Committee of the American Welding Society (8)

Conference Committee (36)

APPROVED SECTIONS OF THE BOILER CONSTRUCTION CODE PUBLISHED BY THE A.S.M.E.

Section I, Rules for the Construction of Power Boilers
Section II, Rules for Materials Specifications
Section III, Rules for the Construction of Boilers of Locomotives
Section IV, Rules for the Construction of Low-Pressure Heating Boilers
Section V, Rules for the Construction of Miniature Boilers
Section VI, Rules for Inspection
Section VII, Suggested Rules for the Care of Power Boilers and Other Pressure Vessels in Service
Section VIII, Rules for the Construction of Unfired Pressure Vessels

RÉSUMÉ

TOTAL NUMBER OF COMMITTEES	389
TOTAL NUMBER OF A.S.M.E. MEMBERS ON COMMITTEES	762
TOTAL NUMBER OF NON-MEMBERS ON COMMITTEES	982
TOTAL NUMBER OF COMMITTEE MEMBERS	1744

Organizations Cooperating With A.S.M.E. Technical Committees

Actuarial Society of America
Aeronautical Chamber of Commerce of America
American Association for the Advancement of Science
The American Boiler Manufacturers Association
American Bureau of Welding
American Bureau of Shipping
American Ceramic Society
American Chemical Society
American Civic Association
American Drop Forging Institute
American Economic Association
American Electrochemical Society
American Electric Railway Association
American Erectors Association
American Foundrymen's Association
American Gas Association, Incorporated
American Gear Manufacturers' Association
American Granite Association
American Hardware Manufacturers Association
American Home Economics Association
American Hospital Association
American Hotel Association of the U. S. and Canada
American Institute of Architects
American Institute of Chemical Engineers
American Institute of Consulting Engineers
American Institute of Electrical Engineers
American Institute of Mining and Metallurgical Engineers
American Institute of Refrigeration
American Institute of Steel Construction
American Management Association
American Marine Standards Committee
American Mathematical Society
The American Mining Congress
American Oil Burner Association
American Paint and Varnish Manufacturers' Association
American Paper and Pulp Association
American Petroleum Institute
American Physical Society
American Psychological Association
American Railway Association
- Engineering Division
  - Rail Committee
  - Track Committee
- Mechanical Division
- Signal Division
- Purchases and Stores Division

American Railway Car Institute
American Railway Tool Foremen's Association
American Refractories Institute
American Society for Testing Materials
American Society of Agricultural Engineers
American Society of Bakery Engineers
American Society of Civil Engineers
American Society of Heating and Ventilating Engineers
American Society of Marine Engineers
American Society of Naval Engineers
American Society of Refrigerating Engineers
American Society of Safety Engineers
American Society for Steel Treating
American Society of Sanitary Engineering
The American Specification Institute
American Standards Association
American Statistical Association
American Steamship Owners' Association
American Supply and Machinery Manufacturers' Association
American Trade Association Executives
American Water Works Association
American Welding Society
American Zinc Institute, Incorporated
Artistic Lighting Equipment Association
Associated Factory Mutual Fire Insurance Companies
Associated General Contractors of America
The Association of American Steel Manufacturers
Association of Edison Illuminating Companies
Association of Electragists International
Association of Governmental Officials in Industry of the U. S. and Canada
Association of Manufacturers of Wood Working Machinery
Association of Operative Millers
Bakery Equipment Manufacturers' Association
Bolt, Nut, and Rivet Manufacturers Association
Building Managers and Owners Association
Canadian Engineering Standards Association
Canning Machinery and Supplies Association
Cap or Set Screw Manufacturers Association
The Cast Iron Pipe Research Association
Casualty Actuarial Society
Chain Institute
Chlorine Institute, Incorporated
Cold Finished Steel Bar Institute
The Commercial Lock Washer Statistical Bureau

The Compressed Air Society
Compressed Gas Manufacturers' Association, Incorporated
Copper and Brass Research Association
Diesel Engine Manufacturers Association
Drill and Reamer Society
Electric Hoist Manufacturers Association
Electric Overhead Crane Institute
Elevator Manufacturers Association of New York
Elevator Manufacturers Association of U. S.
Federal Power Commission
Fire Equipment Manufacturer's Institute
Foundry Equipment Manufacturers Association
Georgia Ice Manufacturers Association
Grain Dealers National Association
Grinding Wheel Manufacturers Association of the U. S. and Canada
Heating and Piping Contractors National Association
The Hydraulic Society
Illuminating Engineering Society
Industrial Commission of Ohio
Institute of American Meat Packers
Institute of Boiler and Radiator Manufacturers
Institute of Radio Engineers
International Acetylene Association
International Association of Fire Chiefs
International Association of Fire Engineers
International Association of Machinists
International Belting Conference
International Electro-Technical Commission
International Association of Industrial Accident Boards and Commissions
Laundryowners' National Association of the U. S. and Canada
Locomotive Crane Manufacturers' Association
Machinery Builders' Society
Manufacturers Standardization Society of the Valve and Fittings Industry
Massachusetts Department of Labor and Industry
Master Boiler Makers' Association
The Mathematical Association of America
Millers' National Federation
Milling Cutter Society
National Academy of Sciences
National Advisory Committee for Aeronautics
National Association of Amusement Parks
National Association of Building Owners and Managers
National Association of Cost Accountants
The National Association of Cotton Manufacturers
National Association of Engine and Boat Manufacturers
National Association of Fan Manufacturers
National Association of Farm Equipment Manufacturers
National Association of Manufacturers of U. S. of America
National Association of Ice Industries
National Association of Master Plumbers of the U. S.
National Association of Mutual Casualty Companies
National Association of Practical Refrigerating Engineers
National Association of Purchasing Agents
National Association of Stationary Engineers
National Association of Steel Furniture Manufacturers
National Automatic Sprinkler Association
National Automobile Chamber of Commerce
National Board of Fire Underwriters
National Bureau of Casualty and Surety Underwriters
National Bureau of Economic Research, Incorporated
National Coal Association
National Conference of Business Paper Editors
National Council on Compensation Insurance
National District Heating Association
National Electric Light Association
National Electrical Manufacturers Association
National Fire Protection Association
National Fire Waste Council
National Founders' Association
National Industrial Conference Board
National Machine Tool Builders' Association
National Metal Trades Association
National Paint, Oil, and Varnish Association, Incorporated
The National Pipe and Supplies Association
National Research Council
National Safety Council
National Slate Association
National Varnish Manufacturers Association
New England Water Works Association
New Jersey Department of Labor
New York State Department of Architects
New York State Department of Labor
Paint Manufacturers Association of the United States
Pennsylvania Department of Commerce and Industry
Pipe Covering Contractors' Association
Pittsburgh Testing Laboratories
Portland Cement Association
Power Piping Society
Power Transmission Association
Printing Press Manufacturers Association
Rail Steel Bar Association
Railway Fire Protection Association
The Refrigerating Machinery Association
Retail Dry Goods Association
The Rubber Association of America
Scientific Apparatus Makers of America
Screw Machine Products Association
The Silk Association of America, Incorporated
Society for the Promotion of Engineering Education
Society of Automotive Engineers
Society of Industrial Engineers
Society of Naval Architects and Marine Engineers
Society of Ohio Safety Engineers
Society of Terminal Engineers
Soil Pipe Manufacturers Association
Southern Supply and Machinery Dealers Association
Sporting Arms and Ammunition Manufacturers' Institute
Steel Founders' Society of America
Stoker Manufacturers Association
Tank and Steel Plate Fabricators
Tap and Die Institute
Taylor Society
Technical Association of the Pulp and Paper Industry
Technical Publicity Association, Incorporated
Terminal Elevator Grain Merchants Association
Underwriters Laboratories
United States Chamber of Commerce
United States Department of Agriculture
  Bureau of Agricultural Economics
United States Department of Commerce
  Bureau of Census
  Bureau of Mines
  Bureau of Standards
  Coast and Geodetic Survey
  Lighthouse Service
  Steamboat Inspection Service
United States Department of Interior
  Geological Survey
United States Department of Labor
  Bureau of Labor Statistics
United States Government Printing Office
United States Independent Telephone Association
United States Interstate Commerce Commission
United States Machine Screw Service Bureau
United States Navy Department
  Bureau of Construction and Repair
  Bureau of Engineering
  Bureau of Yards and Docks
  Design Division
United States Post Office Department
United States Treasury Department
  Bureau of the Public Health Service
United States War Department
  Air Corps
  Ordnance Department
United States Weather Bureau
Water Works Manufacturers Association

Awards

The Committee on Awards, given on page 5, has supervision of the awards of the Society under the direction of the Council. Awards and special funds are administered as specified in the deeds of gift or as may be determined by the Council from time to time. The following awards come within the jurisdiction of the Society:

Honorary Membership, to which persons of acknowledged professional eminence are elected by unanimous vote of Council under the provisions of the By-Laws and Rules. A list of honorary members is given on page 9.

Life Membership, which may be conferred by the Council for distinguished service to the Society.

A.S.M.E. Medal, established by the Society in 1920 to be presented for distinguished service in engineering and science. May be awarded

for general service in science having possible application in engineering.

Holley Medal, instituted and endowed in 1924 by George I. Rockwood, Past Vice-President of the Society, to be bestowed for some great and unique act of genius of engineering nature that has accomplished a great and timely public benefit.

Melville Medal, established in 1914 by the bequest of Rear-Admiral George W. Melville, Honorary Member and Past-President of the Society, to be presented for an original paper or thesis of exceptional merit, presented to the Society for discussion and publication, to encourage excellence in papers. May be presented annually.

Spirit of Saint Louis Medal, endowed by members of the Society and citizens residing in St. Louis, Mo., to be awarded for meritorious service in the field of aeronautical engineering. This medal will be awarded at the discretion of the Council of the Society at approximately three-year periods upon the recommendation of a Spirit of Saint Louis Medal Board of Award made up of six members, each appointed for a term of nine years and the terms of two members expiring at each three-year period.

Junior Award, annual cash award of $50, established in 1914, from a fund created by Henry Hess, Past Vice-President of the Society, to be presented, together with an engraved certificate, for the best paper or thesis submitted by a Junior Member.

Student Awards, two annual cash awards of $25 each, established in 1914, from a fund created by Henry Hess, Past Vice-President of the Society, to be presented, together with engraved certificates, for the best papers or theses submitted by Student Branch Members.

Charles T. Main Award, annual cash award of $150, established in 1919 from a fund created by Charles T. Main, Past-President of the Society, to be awarded to a student of engineering, preferably a member of a Student Branch of the Society, for the best paper within the general subject of the "Influence of the Profession upon Public Life." The exact subject is assigned by the Committee on Awards, subject to the approval of the Council, and is announced each year through the Honorary Chairmen of the Student Branches.

SCHOLARSHIPS AND LOAN FUNDS

Max Toltz: Loan Fund of $15,000 established by Major Max Toltz, former member of the Council of the Society, the income to be used for assistance to students.

John R. Freeman: Fund of $25,000 established in 1926 by John R. Freeman, Past-President of the Society, the income to be used for travel scholarships and research.

Woman's Auxiliary: Scholarship or Fellowship offered by the Woman's Auxiliary to the Society to assist sons and daughters of members or worthy students of mechanical engineering.

RECIPIENTS OF AWARDS

The names of the recipients of the different awards to date are given in the following lists, together with the dates of presentation, and the services or papers for which the awards were made. There were no awards for the years not listed.

A.S.M.E. Medal

1921 Hjalmar Gotfried Carlson, in recognition of the services rendered the Government because of his invention and part in the production of 20,000,000 Mark III drawn steel booster casings used principally as a component of 75-mm. high-explosive shells, but also extensively in gas shells and bombs

1923 Frederick Arthur Halsey, for his paper describing the premium system of wage payments presented before the Society at the Providence Meeting in 1891, as the adoption of the methods there proposed has had a profound effect toward harmonizing the relations of worker and employer

1923 John Ripley Freeman, for his eminent service in engineering and manufacturing by his meritorious work in fire prevention and the preservation of property

1926 R. A. Millikan, in recognition of his contributions to science and engineering

1927 Wilfred Lewis, for his contributions to the design and construction of gear teeth

1928 Julian Kennedy, for his services and contributions to the iron and steel industry

1929 William LeRoy Emmet, for his contributions in the development of the steam turbine, electric propulsion of ships, and other power-generating apparatus.

Holley Medal

1924 Hjalmar Gotfried Carlson, for his inventions and processes which made possible the timely production of drawn steel booster casings for artillery ammunition, thereby aiding victory in the World War

1928 Elmer Ambrose Sperry, for achievements and inventions that have advanced the naval arts, including the gyroscope that has freed navigation from the dangers of the fluctuating magnetic compass

1929 Baron Chuzaburo Shiba, for his contributions to knowledge through fundamental research, including the field of aerodynamics, by the development of ultra-rapid kinematographic methods.

Melville Medal

1927 Leon P. Alford, "Laws of Manufacturing Management"

1929 Joseph Wickham Roe, "Principles of Jig and Fixture Practice"

1930 Herman Diederichs and William D. Pomeroy, "The Occurrence and Elimination of Surge or Oscillating Pressures in Discharge Lines From Reciprocating Pumps."

Spirit of Saint Louis Medal

1929 Daniel Guggenheim, founder of the Guggenheim Fund for the Promotion of Aeronautics.

Junior Award

1915 Ernest O. Hickstein, "Flow of Air Through Thin Plate Orifices"

1916 L. B. McMillan, "The Heat Insulating Properties of Commercial Steam-Pipe Coverings"

1919 E. D. Whalen, "Properties of Airplane Fabrics"

1921 S. Logan Kerr, "Moody Ejector Turbine"

1922 R. H. Heilman, "Heat Losses From Bare and Covered Wrought-Iron Pipe at Temperatures up to 800 Degrees Fahrenheit"

F. L. Kallam, "Preliminary Report on the Investigation of the Thermal Conductivity of Liquids"

1923 S. S. Sanford and S. Crocker, "The Elasticity of Pipe Bends"

1924 R. H. Heilman, "Heat Losses Through Insulating Material"

1925 Gilbert S. Schaller, "An Investigation of Seattle as a Location for a Synthetic Foundry Industry"

1927 Wm. M. Frame, "Stresses Occurring in the Walls of an Elliptical Tank Subjected to Low Internal Pressure"

1928 M. D. Aisenstein, "A New Method of Separating the Hydraulic Losses in a Centrifugal Pump"

1929 Arthur M. Wahl, "Stresses in Heavy Closely Coiled Helical Springs"

1930 Ed Sinclair Smith, Jr., "Quantity-Rate Fluid Meters."

Student Award

1916 Boynton M. Green, Stanford University, "Bearing Lubrication"

Howard Stevens, Rensselaer Polytechnic Institute, "An Investigation of the Dynamic Pressure on Submerged Flat Plates"

M. Adam, Louisiana State University, "The Adaptability of the Internal Combustion Engine to Sugar Factories and Estates"

1917 H. R. Hammond and C. W. Holmberg, Pennsylvania State College, "Study of Surface Resistance With Glass as the Transmission Medium"

1919 C. F. Leh and F. G. Hampton, Stanford University, "An Experimental Investigation of Steel Belting"

W. E. Helmick, Stanford University, "An Experimental Investigation of Steel Belting"

1920 Howard G. Allen, Cornell University, "Wire Stitching Through Paper"

1921 Karl H. White, University of Kansas, "Forces in Rotary Motors"

Richard H. Morris and Albert J. R. Houston, University of California, "A Report Upon an Investigation of the Herschel Type of Improved Weir"

1923 Charles F. Olmstead, University of Minnesota, "Oil Burning for Domestic Heating"

H. E. Doolittle, University of California, "The Integrating Gate: A Device for Gaging in Open Channels"

1924 George Stuart Clark, Stanford University, "Two Methods Used for the Determination of the Gasoline Content of Absorption Oils in Absorption Plants"

L. J. Franklin and Charles H. Smith, Stanford University, "The Effect of Inaccuracy of Spacing on the Strength of Gear Teeth"

1925 Harry Pease Cox, Jr., Rensselaer Polytechnic Institute, "A Study of the Effect of End Shape on the Towing Resistance of a Barge Model"

W. S. Montgomery, Jr., and E. Ray Enders, Jr., Pennsyl-

vania State College, "Some Attempts to Measure the Drawing Properties of Metals"

1926 R. E. Peterson, University of Illinois, "An Investigation of Stress Concentration by Means of Plaster of Paris Specimens"
Cecil G. Heard, University of Toronto, "Pressure Distribution over U. S. A. 27 Aerofoil with Square Wing Tips Model Tests"

1927 Alfred H. Marshall, Princeton University, "Evaporative Cooling"
Roger Irwin Eby, University of Washington, "Measurement of the Angular Displacement of Flywheels"

1928 Clarence C. Franck, Johns Hopkins University, "Condition Curves and Reheat Factors for Steam Turbines"

1929 Frank Vernon Bistrom, University of Washington, "An Investigation of a Rotary Pump"
William Wallace White, University of Washington, "An Investigation of a Rotary Pump"

1930 Gerard Eden Claussen, Polytechnic Institute of Brooklyn, "High-Temperature Oxidation of Steel"
Harold L. Adams and Richard L. Stith, University of Washington, "A Wind Tunnel for Undergraduate Laboratory Experiments."

Charles T. Main Award

1925 Clement R. Brown, Catholic University of America. Subject: "The Influence of the Locomotive on the Unity of the United States"

1926 W. C. Saylor, Johns Hopkins University, Subject: "The Effect of the Cotton Gin Upon the History of the United States During Its First Seventy Years"

1927 No award. Subject: "Scientific Management and Its Effect Upon the Industries"

1928 Robert M. Meyer, Newark College of Engineering. Subject: "Scientific Management and Its Effect Upon Manufacturing"

1930 Jules Podnossoff, Polytechnic Institute of Brooklyn. Subject: "The Value of the Safety Movement in the Industries."

JOINT AWARDS

The A.S.M.E. participates in three joint awards, the Herbert Hoover Medal, the John Fritz Medal, and the Washington Award.

The Herbert Hoover Medal

The Hoover Gold Medal was instituted in 1930 to commemorate the civic and humanitarian achievements of Herbert Hoover and the first award was made to Herbert Hoover on April 8, 1930. From time to time the medal will be awarded by engineers to a fellow engineer for distinguished public service.

The trust fund creating the award was the gift of Conrad N. Lauer, of Philadelphia. The American Society of Mechanical Engineers is the custodian of the fund which is administered by a Board of Award composed of representatives appointed by the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, and the American Institute of Electrical Engineers.

The John Fritz Medal

The John Fritz Medal was established in August, 1902, by the professional associates and friends of the late John Fritz, Past-President and Honorary Member of the A.S.M.E., to perpetuate the memory of his achievement in industrial progress.

The medal is awarded not more than once each year for notable scientific or industrial achievement, with no restrictions on account of sex or nationality. The award is made by a Board of sixteen, four representatives from each of the four national engineering societies, the A.S.C.E., A.I.M.E., A.S.M.E., and A.I.E.E.

The recipients of the John Fritz Medal are given in the following list; there were no awards for the years not listed.

1902 John Fritz, for scientific and industrial achievement

1905 Lord Kelvin, for work in cable telegraphy and other general scientific achievements

1906 George Westinghouse, for the invention and development of the air brake

1907 Alexander Graham Bell, for the invention and introduction of the telephone

1908 Thomas Alva Edison, for the invention of the duplex and quadruplex telegraph; the phonograph; the development of a commercially practical incandescent lamp; the development of a complex system of electric lighting, including dynamos, regulating devices, underground system, protective devices, and meters

1909 Charles Talbot Porter, for his work in advancing the knowledge of steam engineering and improvements in engine construction

1910 Alfred Noble, for notable achievements as a civil engineer

1911 Sir William Henry White, for notable achievements in naval architecture

1912 Robert Woolston Hunt, for his contributions to the early development of the Bessemer process

1914 John Edson Sweet, for his achievements in machine design; and for his pioneer work in applying sound engineering principles to the construction and development of the high-speed steam engine

1915 James Douglas, for notable achievements in mining, metallurgy, education, and industrial welfare

1916 Elihu Thomson, for achievements in electrical invention, in electrical engineering and industrial development, and in scientific research

1917 Henry Marion Howe, for his investigations in metallurgy, especially in the metallography of iron and steel

1918 J. Waldo Smith, for achievement as an engineer in providing the City of New York with a supply of water

1919 George W. Goethals, for achievement as builder of the Panama Canal

1920 Orville Wright, for achievement in the development of the airplane

1921 Sir Robert A. Hadfield, for the invention of manganese steel

1922 Charles Prosper Eugene Schneider, for achievement in metallurgy of iron and steel, for development of modern ordnance, and for notable patriotic contribution to the winning of the World War

1923 Senator Guglielmo Marconi, for the invention of wireless telegraphy

1924 Ambrose Swasey, for achievement as a designer and manufacturer of instruments and machines of precision, a builder of great telescopes, a benefactor of education, the founder of the Engineering Foundation

1925 John Frank Stevens, for great achievements as a civil engineer, particularly in planning and organizing for the construction of the Panama Canal; as a builder of railroads, and as administrator of the Chinese Eastern and Siberian Railways

1926 Edward Dean Adams, for great achievements as engineer, financier, scientist, whose vision, courage and industry made possible the birth at Niagara Falls of hydroelectric power

1927 Elmer Ambrose Sperry, for the development of the gyrocompass and application of the gyroscope to the stabilization of ships and aeroplanes

1928 John Joseph Carty, for pioneer achievement in telephone engineering and in development of scientific research in the telephone art

1929 Herbert Hoover, engineer, scholar, organizer of relief to war-stricken peoples, public servant.

1930 Ralph Modjeski, for notable achievement as an engineer of great bridges combining the principles of strength and beauty

1931 Admiral David Watson Taylor, for outstanding achievement in marine architecture, for revolutionary results of persistent research in hull design, for improvement in many types of warships, and for distinguished service as Chief Constructor of the United States Navy during the World War.

The Washington Award

The Washington Award was founded in 1916 by John Watson Alvord, to be awarded annually by the Western Society of Engineers upon the recommendation of a Commission composed of nine representatives of that society and two representatives of each of the four national engineering societies, the A.S.C.E., A.I.M.E., A.S.M.E., and A.I.E.E. It is bestowed in recognition of devoted, unselfish, and preeminent service in advancing human progress through engineering. The recipients have been as follows:

1919 Herbert C. Hoover, for his preeminent services in behalf of the public welfare

1922 Robert W. Hunt, for his pioneer work in the development of the steel industry, and for a life devoted to the advancement of the engineering profession

1923 Arthur N. Talbot, for his life work as a student and teacher, investigator and writer, and for his enduring contribution to the science of engineering

1925 Jonas Waldo Smith, for the rare combination of vision, technical skill, and administrative ability and courageous leadership in engineering

1926 John Watson Alvord, for his pioneer work in developing the fundamental principles of public utility valuation and his marked contributions to sanitary science

1927 ORVILLE WRIGHT, for fundamental scientific research and the resultant successful airplane flight

1928 MICHAEL I. PUPIN, for devotion to scientific research leading to his inventions which have materially aided the development of long-distance telephony and radio broadcasting

1929 BION JOSEPH ARNOLD, for pioneering work in the engineering and economics of electrical transportation

1930 MORTIMER ELWYN COOLEY, for vision and constructive leadership in the education of the engineer.

Summary of Membership

(January 2, 1931)

SUMMARY OF MEMBERSHIP BY GRADES

Honorary Members	25
Members	8836
Associates	594
Associate-Members	3940
Juniors	5754
Total	19149

MEMBERSHIP BY RESIDENCE

UNITED STATES

Alabama	111	Nevada	4
Arizona	19	New Hampshire	32
Arkansas	17	New Jersey	1471
California	823	New Mexico	5
Colorado	100	New York	4901
Connecticut	608	North Carolina	91
Delaware	101	North Dakota	7
District of Columbia	191	Ohio	1206
Florida	64	Oklahoma	100
Georgia	127	Oregon	69
Idaho	8	Pennsylvania	2079
Illinois	1269	Rhode Island	163
Indiana	327	South Carolina	35
Iowa	64	South Dakota	7
Kansas	66	Tennessee	122
Kentucky	52	Texas	225
Louisiana	103	Utah	37
Maine	38	Vermont	38
Maryland	233	Virginia	177
Massachusetts	1159	Washington	123
Michigan	676	West Virginia	72
Minnesota	134	Wisconsin	417
Mississippi	25	Wyoming	9
Missouri	353		
Montana	14	Total	18101
Nebraska	29		

UNITED STATES' POSSESSIONS

Alaska	1	Philippine Islands	29
Canal Zone	7	Porto Rico	34
Hawaii, Territory of	24	Total	95

OTHER COUNTRIES

NORTH AMERICA			
Canada	283		
Mexico	37		
		—	320
CENTRAL AMERICA			
Costa Rica	4		
Panama	1		
		—	5
WEST INDIES			
Aruba	1		
Cuba	44		
Dominican Republic	6		
Haiti	2		
		—	53
SOUTH AMERICA			
Argentina	20		
Bolivia	1		
Brazil	12		
British Guiana	2		
Chile	27		
Colombia	8		
Ecuador	1		
Peru	8		
Uruguay	2		
Venezuela	7		
		—	88
AFRICA			
Egypt	3		
Northern Rhodesia	2		
Spanish Morocco	1		
Union of South Africa	10		
		—	16
ASIA			
Ceylon	1		
China	23		
Dutch East Indies	1		
Federated Malay States	1		
India	57		
Japan	30		
Manchuria	1		
Persia	2		
Siam	1		
		—	117
AUSTRALASIA			
Australia	35		
New Zealand	6		
		—	41
EUROPE			
Austria	4		
Belgium	4		
Czechoslovakia	7		
Denmark	7		
Finland	2		
France	41		
Germany	54		
Great Britain	117		
Greece	2		
Holland	5		
Italy	9		
Norway	6		
Poland	5		
Portugal	1		
Roumania	2		
Spain	6		
Sweden	11		
Switzerland	12		
Syria	1		
Turkey	3		
Union of Soviet Socialist Republics	11		
		—	310
Total			950

SUMMARY OF MEMBERSHIP BY RESIDENCE

Membership in United States	18101
Membership in United States' Possessions	95
Membership in Other Countries	950
Present Address Unknown	3
Total Membership	19149

Report of Council

THE Council presents its report for the administrative year 1930. The personnel of the Council for 1930 is given on page 5 of this Section of Transactions.

The Council records with deep regret the death of Elmer A. Sperry, President of the Society in 1929, and Dr. Ira N. Hollis, President in 1917, and Honorary Member of the Society, as well as Chairman of the Committee on Awards.

Fiftieth Anniversary of the Society

Outstanding in events of the year was the celebration of fifty years of the organization of the A.S.M.E. This was held April 5–9 in New York, Hoboken, and Washington, D. C. The message from your President, Charles Piez, in the April, 1930, issue of *Mechanical Engineering*, gives not only a brief and splendid review of the past, but a challenge to the future interpreting the motto on the anniversary medal, "What is not yet, may be." This anniversary brought out our honor roll of the living founders, whose names are here recorded, several of whom were able to be present at the Founders' Luncheon in Washington on Tuesday, April 8. They are John W. Cloud, London, England, John S. Coon, Atlanta, Georgia, Robert F. Grimshaw, New York, N. Y., Francis H. Richards, New York, N. Y., Eugene H. Robbins, Pittsfield, Mass., and Ambrose Swasey, Past-President and Honorary Member, Cleveland, Ohio.

Hoover Medal. The Hoover Medal, made possible through the generous gift of Conrad N. Lauer, Vice-President of the Society, was instituted on the occasion of the Anniversary Dinner, Tuesday evening, to commemorate the civic and humanitarian achievements of an engineer; the medal is "to be awarded by engineers to a fellow engineer for distinguished public service," and was awarded to Herbert Hoover, as the first recipient, "whose humanitarism knew no national lines."

The Fiftieth Anniversary brought to this country, as a part of our program, a group of distinguished engineers from foreign countries.

The convocation ceremonies, at which were presented the fiftieth anniversary medalists, were held on Tuesday, April 8, in the assembly hall of the U. S. Chamber of Commerce, Washington, D. C. The chief diplomatic officer of each country represented on this occasion, presented to the Society for the conferring of the medal, the distinguished engineer who had been selected for this honor by the engineering profession of his country.

Membership

The chart on this page shows the changes in membership corresponding to the fiscal year of the Society. At the close of the administrative year of 1930 and the time of the writing of this report, the membership totals 20,047.

Standing and Special Council Committees

An outstanding accomplishment in this year's activities has grown out of the petroleum industry in Oklahoma, centering around the Mid-Continent Section at Tulsa. Through the combined efforts of the Local Sections Committee, the Professional Divisions, and a special research committee the Society began a service to the industry by the establishment of an educational laboratory for automatic pumping-station equipment. This represents on the part of industry, an investment of $50,000, and is the first automatic crude oil pumping station for pipe-line companies to be maintained as a permanent proving ground for the development of this type of apparatus. The Boiler Code Committee conferred with the representatives of this industry preparatory to a revision of the Code of Unfired Pressure Vessels to meet the needs of the petroleum industry. The Special Research Committee on Fluid Meters held a meeting in Norman, Okla., for the expressed purpose of studying the special needs of this industry in the measurement of natural gas. The A.S.M.E., through the cooperation of the Publications Committee, issued a special publication, *Petroleum Mechanical Engineering.* The Petroleum Division's Section of Transactions will hereafter be called *Petroleum Mechanical Engineering.* A part-time staff representative has been set up at Tulsa.

The reports of the Standing Committees, together with the report of the Boiler Code Committee, form an appendix to this record. "Fifty Years of the A.S.M.E.," as given on the occasion of our Fiftieth Anniversary, and printed in the April, 1930, issue of *Mechanical Engineering*, is an inclusive statement of the development of our various committees. Other special Council committees reporting this year are the Revenues Committee appointed in 1929 to study the possibilities of increasing the Society's income, of decreasing its expenditures, and of making such recommendations as might arise out of this study, looking toward the Society's operating efficiency. This resulted in the recommendation of a slight increase in the initiation fees in certain grades with the purpose of (1) increasing the income from initiation fees, and (2) providing a greater distinction between the grades of Associate Member and Member. The income from initiation fees becomes a part of the invested reserve of the Society. The result of the ballot on amendments shows a favorable ballot of 4762 for, and 1376 against. The amendments become effective on announcement at this Annual Meeting.

MEMBERSHIP CHANGES—OCTOBER 1, 1929, TO SEPTEMBER 30, 1930

	Membership			Losses			Additions			Totals		
	Oct. 1, 1929	Oct. 1, 1930	Trans. from	Resigned	Dropped	Died	Trans.	Elect.	Reinstated	Loss	Gain	Net Changes
Honorary Members	24	24				2	2			2	2	...
Life Members	75	74				3	2			3	2	− 1
Members	8720	8955	4	97	168	106	141	445	24	375	610	235
Associates	634	632	5	15	17	10		43	2	47	45	− 2
Associate-Members	4178	4175	110	64	205	12	74	296	18	391	388	− 3
Juniors (20)	1172	1558	65	59	111	5	626			240	626	386
Juniors (10)	4634	4593	661	96	237	4		951	6	998	957	−41
	19,437	20,011	845	331	738	142	845	1735	50	2056	2630	574

Finances. The report of the auditors for the fiscal year of the Society, October 1, 1929, to September 30, 1930, follows as part of the Finance report. Attention is called to the bequests of $23,250 of the late Worcester Reed Warner, Past-President and Honorary Member of the Society, and of C. B. F. Waller, member of the Society, who left the residue of his estate of some $7000 to the Society.

All trust funds are carefully invested by the Council under the legal requirements for trust funds in the State of New York, and the interest on the respective fund in most cases provides for the awards made under such gifts.

Each year's summing-up reveals an increase in industrial support for the experimental programs in research and the expenditures during the past year from cash contributions made by industry have totaled approximately $50,000, or more than three times the Society's research budget for the same period. At the present time the Society is custodian for the funds of

thirty-three (33) research committees, these funds being contributed by industry and The Engineering Foundation.

Student Branches. There are now 106 Student Branches. The conferences held at the Annual and Semi-Annual Meetings with delegates coming from the various branches, show an intensive interest in Society work. From the ranks of these young engineers, much of the membership of the future A.S.M.E. will be recruited.

Budgeting Policy Committee. This Committee since its formation has focused its discussion on the need for formulation of a definite program of Society activity in distinction from a financial program and the translation of the work program into expenditures.

The Committee on Economic Status of the Engineer was formed in May, 1928. This Committee is actively at work but has before it a most difficult, involved, and extended study and task. The Employment Service and Local Sections are cooperating in certain phases of the study which the Economic Status Committee is making.

Joint Activities and Representation

Employment Service. The Employment Service shows quite marked geographical development. For years it has had to function without the guidance of a committee. Now we are gratified to have the watchful care of the Committee on Local Sections. This service is a joint undertaking of the four national engineering societies and offices are maintained in New York, San Francisco, and Chicago.

A consultation of the membership list will give some idea of the varied general activities and the largely diversified appointments, both geographically and professionally, which are covered during a Society year. With the adherence last year of the American Society of Civil Engineers, the American Engineering Council is now a body representative of the profession. The A.S.M.E. has twenty representatives.

Other organizations in which we have joint interest and representation are the American Standards Association, the Engineering Foundation, the Engineering Societies Trustees, Inc. (the latter the holding corporation for the founder societies of the Engineering Building), the A.A.A.S., the Museums of the Peaceful Arts, Gantt Medal Board of Award, Guggenheim Medal Board, the U. S. National Committee of the International Electrotechnical Commission, John Fritz Medal Board of Award, the Hoover Medal Board, Joseph A. Holmes Safety Association, the Division of Engineering of the National Research Council, National Safety Council, the Alfred Noble Prize, the Spirit of St. Louis Medal Board of Award, and the Washington Award of the Western Society of Engineers.

We also have assignments on federal and civic organizations having to do with engineering problems. Both in our committee work and in general the President and Council are called on to make appointments for a great variety of occasions. This year, at home and abroad, the Society has been represented at many international congresses and special celebrations. For these latter events Honorary Vice-Presidents are chosen by the Council to represent the Society.

In the summary of the year's activity, the Council has touched only briefly. Your attention is especially called to the splendid reports of our Committees accompanying this summary to give you the more detailed accounts, and Council would again record its gratitude and appreciation to the Committeemen and to authors who have given of their time and talents and the benefits of their experience for the general good and for the advancement of our profession.

Calvin W. Rice,
Secretary.

FINANCE

The year 1929–1930 was a successful financial period in the Society's operation. The excess of income over expenditures was $39,069.33, of which $5000 went into the Retirement Fund. Five thousand dollars was added to the special reserve for Engineering Index Development and the total reserves were therefore increased by $44,069.33.

The Engineering Index passed through the third year of its development period and is at a point where, barring possibility of general loss in income due to business conditions, it will become self-supporting and may possibly produce a small amount of income.

$120,000 was borrowed to tide over the end of the fiscal year as compared to $80,000 for the same purpose the previous year. It should be explained that this financing is usually necessary as Mechanical Catalog billings are not made until September 30, the last day of the fiscal year, while expenditures against that income are incurred uniformly throughout the year. The increase this year was largely due to the expense for the Fiftieth Anniversary which is to be financed over a period of years.

The accompanying table giving the condensed comparison of the balance sheet for the year ending September 30, 1929, with that of the year just closed reveals increases in all of the items except one. These increases are explained in the following paragraphs.

CONDENSED STATEMENT OF INCOME AND EXPENDITURES
1928-1929 AND 1929-1930

	1928-1929	1929-1930
Income		
Initiation Fees	$ 29,769.02	$ 30,430.17
Membership Fees	303,272.09	314,815.87
Accounts Receivable (Members and Non-Members)	411,878.96	445,233.18
Interest	22,655.50	23,601.18
	$767,575.57	$814,080.40
Appropriated from 1927-1928 Excess Income.	10,000.00	
	$777,575.57	
Expenditures		
Administration and General	$119,068.38	$104,152.33
Initiation Fees Account	25,595.37	21,802.81
Service to Members Account	282,086.38	319,381.46
Income Producing and Professional	271,032.63	300,018.64
Reserve for Engineering Index Development.	20,000.00	5,000.00
Service to Public Account	24,659.42	24,676.49
	$742,442.18	$775,031.73
Preceding year's liability for Mechanical Catalog: Underexpended	521.84	20.66
	$741,920.34	$775,011.07
Balance of Income over Expenditures	$ 35,655.23	$ 39,069.33

CONDENSED COMPARISON OF BALANCE SHEETS

	Sept. 30, 1929	Sept. 30, 1930	Net Charge During Fiscal Year
Assets			
Cash	$ 4,367.49	$ 6,965.99	$+ 2,598.50
Accounts Receivable	160,412.58	166,150.97	+ 5,738.39
Inventory	101,378.05	114,873.36	+13,495.31
Deferred Charges	107,942.06	171,201.14	+63,259.08
Investment for Trust Funds	134,315.85	164,035.45	+29,719.60
Investment for Capital Account	332,381.25	343,381.25	+11,000.00
Fixed Assets	514,673.80	515,682.34	+ 1,008.54
Total Assets	$1,355,471.08	$1,482,290.50	$ 126,819.42
Liabilities			
Current Liabilities	$ 133,578.11	$ 184,803.95	$+51,225.84
Contributions for Research	22,453.48	23,757.09	+ 1,303.61
Dues Paid in Advance	4,473.09	4,349.81	− 123.28
Trust Funds	134,315.85	164,035.45	+29,719.60
Capital	1,060,650.55	1,105,344.20	+44,693.65
Total Liabilities	$1,355,471.08	$1,482,290.50	$ 126,819.42

Accounts Receivable. The increase in this item is due to the increase in income from the Mechanical Catalog over the income for 1928–1929.

Inventory. This increase is due to a larger program of publications in process and in stock awaiting sale.

Deferred Charges. The change under this heading is due to the expenses for the Fiftieth Anniversary which are to be financed over several years and to the increase in the development costs of the Engineering Index.

Trust Funds. The Spirit of St. Louis Medal Fund of $3500 and the Worcester R. Warner Prize Fund of $23,250 account for part of this increase. The remainder of the increase is due to increases in existing funds.

Capital Account. This increase represents an investment of funds in the Capital Account.

Current Liabilities. The change in this item is best shown by the following table:

	Sept. 30, 1929	Sept. 30, 1930
Notes Payable	$ 80,000.00	$120,000.00
Liabilities for Unfilled Commitments	51,507.51	43,937.28
Historical Bibliography (Hollis Gift)	320.60	
Thurston Biography (Gleason Gift)	1,750.00	460.82
Accounts Payable		20,405.85
	$133,578.11	$184,803.95

Increase in the item of notes payable has been explained in the preceding paragraph. The new item of accounts payable is due to a large amount of printing bills for Transactions which came due at the close of the fiscal year.

Capital. Change in Capital Account is explained by the following table:

	Sept. 30, 1929	Sept. 30, 1930
Fixed Assets	$ 514,673.80	$ 515,682.34
Reserve for Retirement Allowance	20,608.00	26,232.32
Appropriated for Investment	322,137.62	317,148.93
Reserve for Engineering Index Development	20,000.00	25,000.00
Working Capital	183,231.13	221,280.61
	$1,060,650.55	$1,105,344.20

William J. Struss & Co., Certified Public Accountants, give the results of their examination of the books of the Society for the fiscal year ended September 30, 1930, in the accompanying statement of Assets and Liabilities.

Respectfully submitted,

F. A. SCHAFF, *Chairman*
DAVID LOFTS, *Vice-Chairman*
JAMES L. WALSH
KINGSLEY L. MARTIN
JOHN H. LAWRENCE
WM. ELMER } *Council*
H. V. COES } *Representatives*

STATEMENT OF FINANCIAL CONDITION, SEPTEMBER 30, 1930

ASSETS

Cash		$ 4,993.58
Accounts Receivable:		
Members	$ 30,729.41	
Non-Members	135,421.56	166,150.97
Savings Banks		1,972.41
Inventories:		
Supplies	33,359.82	
Publication in Process	22,461.05	
Publication for Sales	59,052.49	114,873.36
Investments for Trust Funds (see contra):		
First Mortgage and Mortgage Bonds on Real Estate 5½%	77,000.00	
St. Louis, Peoria & N.W.R.R. 5% 1948	10,613.89	
N. Y. Central & Hudson Riv. R.R. 4% 1942	23,062.50	
Stock Shares (J. R. Freeman)	26,279.78	
Cash in Banks	27,079.28	164,035.45
Investments for Capital Account:		
First Mortgage & Mortgage Bonds on Real Estate 5½%	273,500.00	
Alabama Pwr. & Light Co. 5% 1951	5,000.00	
Texas Pwr. & Light Co. 5% 1956	4,850.00	
Dallas Pwr. & Light Co. 5% 1952	5,000.00	
San Diego Consolidated Gas & Elec. 5% 1947	5,075.00	
Binghampton L.H.&P. 5% 1946	5,000.00	
Commonwealth Edison Co. 5% 1953	5,118.75	
Metropolitan Edison Co. 5% 1953	5,012.50	
Public Service Co. of Ill. 5% 1966	4,962.50	
Cumberland Power & Light 4½% 1956	4,725.00	
Baltimore & Ohio R.R. 5% 2000	5,115.00	
Baltimore & Ohio R.R. 4½% 1933	4,947.50	
Alabama Power Co. 5% 1968	4,975.00	
Central Maine Power 5% 1955	10,100.00	343,381.25
Fixed Assets (Book Value):		
Building	493,352.60	
Furniture and Equipment	22,327.74	
Library Books	1.00	
Engineering Index	1.00	515,682.34
Deferred Charges:		
Activities Chargeable to next year	45,219.69	
Loan to New Engineering Index Service (including furniture)	110,981.45	
Loan to Physical Properties of Steam	15,000.00	171,201.14
		1,482,290.50

LIABILITIES

Notes Payable		$ 120,000.00
Accounts Payable		20,405.85
Unfilled Commitments		43,937.28
Gift for Thurston Biography		460.82
Custodian Funds (33)		23,757.09
Dues paid in advance		4,349.81
Trust Funds (see contra):		
Life Membership Fund	$ 55,187.29	
Library Development	6,451.59	
Weeks Legacy	2,565.27	
Melville	1,750.82	
Charles T. Main	3,115.79	
Hunt Memorial	254.59	
Hess Awards—Junior and Senior	2,000.00	
A.S.M.E. Research	611.63	
Westinghouse Bust	190.91	
Holley Medal	6,577.37	
Max Toltz	15,936.82	
John R. Freeman	27,643.37	
Herbert Hoover Medal	15,000.00	
Spirit of St. Louis	3,500.00	
Worcester R. Warner	23,250.00	164,035.45
Capital Investment:		
In Fixed Assets	515,682.34	
Reserve for Retirement Allowance	26,232.32	
Appropriated for Investment	317,148.93	
Working Capital	221,280.61	
Reserve for Engineering Index Development	25,000.00	1,105,344.20
		1,482,290.50

MEETINGS AND PROGRAM

In the successful Semi-Centennial Anniversary Meeting several years' planning and activity by the Committee on Meetings and Program was brought to fruition. For more than five years the Committee on Meetings and Program had worked continuously on the plans for the celebration. The success of this event, therefore, is the result of the contributions of all of those who served on the Committee during that period and the members of the present Committee take great pleasure in thus acknowledging them.

The Anniversary meeting in Washington is the outstanding activity of the Committee on Meetings and Program during the fiscal year. It has been recorded fully in the publications of the Society and further detail is not necessary here. Suffice it to say that the objects of the Committee in the celebration were reached in that the celebration brought together representatives of the engineers of the world, focused the attention of the profession on its broader responsibilities, and was conducted in a manner befitting the standing of the Society.

Three other meetings were held during the year at Akron in October, 1929, the Annual Meeting in New York in December, 1929, and the Semi-Annual Meeting at Detroit in June, 1930.

AKRON MEETING

The Akron Meeting dealt with topics of interest to the industries in and about Akron. The dinner provided the platform for an address by W. E. Wickenden, President of the Case School of Applied Science, and for the first appearance before the Society of the President-Elect, Charles Piez. An exceedingly interesting program of inspection trips to the rubber plants of Akron attracted a goodly attendance.

ANNUAL MEETING

The Annual Meeting was the usual successful event, the registration being 2215. The presence of President Sperry at the World Engineering Congress in Japan required a slight change in the usual program and in place of the presidential address two addresses were given, one on "Economic Changes," by E. E. Hunt, and the second on "Engineers and American Life," by L. W. Wallace and J. E. Hannum. Dr. James Rowland Angell, President of Yale University, was the speaker at the dinner.

At the Knoxville and Akron meetings, the experiment was tried of eliminating the reporter from the sessions. These preliminary trials proved successful and this procedure was followed at this Annual Meeting. It also proved successful.

The Philadelphia Local Section cooperated by conducting the Open House on the opening evening of the meeting.

DETROIT MEETING

The Detroit Committee very wisely eliminated from their plans for the meeting the usual formal events and concentrated their efforts on making the meeting a success socially in an informal way. They provided an excellent program of visits to the interesting plants in Detroit as well as a boat trip for the entire party on the Detroit River and to Lake St. Clair.

A technical program of sixteen sessions provided a goodly amount of valuable material.

COMMITTEE REUNION

The Committee celebrated the completion of twenty-five years of its history by a reunion dinner on February 20, 1930. Thirty-seven members had served on the Committee since its inception in 1904 and seventeen of them were present at the dinner which was given over to reminiscences of Committee activities and suggestions as to forward-looking projects which the Society should undertake.

Respectfully submitted,

W. L. BATT, *Chairman*
G. M. EATON
F. M. FEIKER
J. W. PARKER
C. P. BLISS.

MEMBERSHIP

The Committee on Membership held eighteen meetings during the fiscal year 1929–1930.

The number of applications considered in the transaction of its work and a summary showing the action taken follows:

Applications pending, October 1, 1929	457
Applications received during fiscal year 1929-1930	1892
Total applications handled during year 1929-1930	2349
Recommended for membership	2018
Transfers denied	3
Deferred	1
Withdrawn	35
Applications pending, October 1, 1930	292
Total applications handled during year 1929-1930	2349

Those recommended for membership were divided into the following grades:

Members	442
Transfers to Member	140
Associates	51
Transfer to Associate	1
Associate-Members	338
Transfers to Associate-Member	82
Juniors	443
Juniors (R5 Rule 1)	521
Total recommended	2018
Transfers	223
Total new members recommended	1795

During the fiscal year 1929-1930 the Membership Committee made the following recommendations:

Elections declared void	149
Resignations accepted	330
Dropped from membership	692
Total loss	1171

Respectfully submitted,

L. K. COMSTOCK, *Chairman*
F. A. WALDRON
H. W. BUTLER
H. WEBSTER
O. E. GOLDSCHMIDT.

PUBLICATIONS

The outstanding event of the year ending September, 1930, was the celebration of the Fiftieth Anniversary of The American Society of Mechanical Engineers. To this successful celebration the Publications Committee contributed the special anniversary issue of *Mechanical Engineering* which was published in April. The issue featured the historical development of the Society, the engineers of the period who achieved prominence by reason of election to honorary membership, or to the presidency of the Society, and contemporaneous technological progress. The Society's Professional Divisions, by committees or through individuals, appointed to do so, prepared excellent historical surveys of progress in their fields, thus contributing notably to the history of engineering.

Mechanical Engineering has continued its program of publishing material of appeal to the widely varying interests of the diversified membership of the Society and of treating of matters of professional importance to all engineers. The summarizing leaflet, written in popular style, and intended to give a hasty survey of the papers of principal interest in *Mechanical Engineering*, has continued to be published as Section Two. Illustrations were introduced into most of this year's issues of this leaflet with good effect. The *Literary Digest* has been attracted to articles in the Society's Journal through the medium of Section Two and has commented on its articles in consequence.

The Transactions appeared bound in two volumes late in the spring of 1930. The rapidly increasing size of the Transactions has given the Committee some concern and is likely to result in a more careful scrutiny of papers offered for publication in the hopes of increasing quality and keeping publication costs within the budget.

Volume 3 of the Record and Index of the Society was published in September, 1930. After careful study of the problems the Publications Committee recommended to the Council that in the future the Record and Index be published as a section of the Transactions in pamphlet form similar to other sections issued by the Professional Divisions. The Council has approved this change, which is to take effect at once. There is thus restored to Transactions the Society Affairs material that it previously contained, and the Record and Index will cease to exist as a special publication in its present form.

The *A.S.M.E. News* has continued to give gratifying signs of filling the need for which it was intended. Interest in it is evident from the number of letters received on items published in its columns. The Committee has undertaken a study of a comprehensive plan for increasing the valuable service that the *News* renders.

As a result of the activities of the Applied Mechanics Division and its intense interest in subjects in its field that are highly specialized, the Publications Committee, with consent of Council, has been able to induce the McGraw-Hill Book Company to publish a book on "Plasticity," by A. Nadai. By means of the cooperative arrangements made, the publisher is assured of a favorable reception of the book and the engineering profession has an accession of great value to its literature on a little-known subject of rapidly growing importance. The Society expects to sponsor the publication of other books in a similar manner.

The sixteen eminent engineers of the world who were awarded the Fiftieth Anniversary Medal at the Society's Anniversary Celebration submitted monographs as to the technological and humanistic aspects of engineering progress in their respective countries. The Committee is pleased to report that Mr. Harrison W. Craver, librarian of the Engineering Societies Library, has consented to edit these monographs for publication. The work is now in progress and an early publication in book form of all of the monographs is expected.

As evidence of notable progress in the work of the Society's research committee on the thermal properties of steam, the Publications Committee reports the publication in the Spring of 1930 of "Steam Tables and Mollier Diagram," by Joseph H. Keenan. This important set of tables is published by the Society and has met with favorable notice; it is rapidly being adopted by the profession and by educational institutions.

In its reports of last year the Committee mentioned the proposed symposium by engineers edited by Dr. Charles A. Beard and published by Longmans, Green and Company. The symposium was published in April, 1930, under the title "Toward Civilization" and has been favorably reviewed and received. The Committee feels that its efforts in interesting Dr. Beard in the project have been well repaid by the opportunity which engineers have had of expressing their views in the present discussion of the mechanization of civilization.

Intense interest in the mechanical engineering problems involved in the petroleum industry has been a feature of the past year. The Publications Committee, wishing to further this interest, authorized, at the suggestion of the Petroleum Division, the publication of a special preprint known as *Petroleum Mechanical Engineering*, containing the papers to be presented at the National meeting of the Petroleum Division held in Tulsa, Okla., October 6 to 8, 1930. The expense of this unusual publication was met by special advertising solicited for printing as part of the pamphlet. Explanation of the objects and organization of the Society and the Petroleum Division were included, as were also an abstract of a historical article on the petroleum industry which appeared in the April issue of *Mechanical Engineering*, and a special selection of references to the contemporary technical literature of the oil industry supplied by The Engineering Index.

The Engineering Index Service

The marked progress made by The Engineering Index Service during the past year indicates that it may be no longer considered a speculative venture. The income for the fiscal year 1929-1930 has more than equaled the budget. The number of subscribers has increased more than fivefold, indicating that the value of the Service is being more widely recognized.

At the beginning of the fiscal year, the divisions of the Service were completely revised, to meet more adequately the needs of subscribers, which, together with some added features, have greatly broadened the effectiveness of the Service. At the same time, the subscription prices were reduced, many divisions now being priced as low as $7 per year, and the complete Service, $1500 per year.

The list of periodicals reviewed by the Service has been materially extended during the past year. Not only the regular, but also all irregular publications received by the Engineering Societies Library, except books, are now being reviewed. In addition, the reviews of new books, which are prepared regularly by the Library, are included in the Service.

Respectfully submitted,

W. A. Shoudy, *Chairman*
F. V. Larkin
W. H. Winterrowd
L. C. Morrow
S. F. Voorhees.

PROFESSIONAL DIVISIONS

During the last year the Professional Divisions have continued their splendid program of activities. Besides the usual activities of securing technical papers for Society and Divisional meetings, preparing their yearly progress reports, and developing research projects, there has been a noticeable increase of the activities of subcommittees functioning directly under the Divisions and doing some very constructive work. The table of Divisions' activities shows that 246 papers were secured and presented by the Divisions during the year. This does not include papers presented by them at usual Metropolitan Section meetings, or Division reports.

Petroleum Division

The most outstanding development of the year was the activity in the petroleum field. This was due to the splendid work of the Mid-Continent Section, aided by special financial assistance given the Petroleum Division by Council. As a result a number of active subcommittees were gotten under way and a large national meeting was held in Tulsa, October 6, 7, and 8, during the Petroleum Exposition.

The activities of this Division were divided into six subcommittee groups, three of which functioned primarily in the East and three at Tulsa. They have all given during the year splendid evidence of the valuable work they can do. One of them, on Lubrication Engineering, takes care of a long-expressed need, giving the practical lubrication engineer the opportunity of having a forum of his own. The Refining Committee, besides presenting an admirable program at the Tulsa meeting, has made a survey of possible research projects and is doing excellent work in developing support for A.S.M.E. research projects of value to petroleum refining. The utilization of petroleum as a fuel is under the direction of a committee which is providing a paper at Tulsa and a meeting in New York this winter.

The group in Tulsa initiated and sponsored the program there which included the forming of three subcommittees on Oil Transportation, Gas Transportation, and Production. The Tulsa group also have accomplished splendid committee work on problems of keen local interest, such as automatic pumping stations. The latter has culminated in the building of a demonstration automatic pumping station at the Petroleum Exposition which has received a good deal of favorable comment.

Other Divisions

Other Divisions have been functioning well during the past year. Special attention might be called to some outstanding activities. The Iron and Steel Division and the Machine Shop Practice Division cooperated in the Metal Congress in Chicago during the week of September 22. Our Society was one of four Societies holding simultaneous meetings during the week, and more than fourteen hundred members of the Society attended the Congress, attracted by the splendid program presented by the various groups.

Other interesting joint activities during the year were the national meetings of the Materials Handling and Management Divisions held at the time of a Management Congress in Chicago last March. A

PROFESSIONAL DIVISIONS ACTIVITIES IN 1930—FOUR-POINT PROGRAM

	Aeronautic	Applied Mechanics	Fuels	Hydraulic	Iron and Steel	Machine Shop Practice	Management	Materials Handling	National Defense	Oil and Gas Power	Petroleum	Power	Printing Industries	Railroad	Textile	Wood Industries	Total, 1930	Total, 1929
1 *Society Meetings*[1]																		
(Semi-Annual, Regional, Annual)																		
(a) Number of sessions	3	8	2	2	1	5	4	4	0	1	0	6	1	3	1	2	43	36
(b) Number of papers	9	16	4	5	2	11	6	7	0	2	0	10	3	6	1	5	87	81
2 *Division Meetings*																		
(a) Number of meetings	4[2a]	0	0[3]	0	1	1	1[2b]	1[2c]	0	1	1	0	2[2d]	0	1	1	14	13
(b) Number of sessions	16	0	0	0	4	4	1	5	0	5	6	0	6	0	1	3	51	57
(c) Number of papers	45	0	0	0	9	8	4	13	0	17	25	0	26	0	2	10	159	162
(d) Attendance, members	475	0	0	0	700	700	.	400	0	240	175	0	300	0	110	90	3190	2615
(e) Attendance, non-members	300	0	0	0	100	100	.	480	0	120	125	0	400	0	50	120	1795	2021
(f) Attendance, total	775	0	0	0	800	800	.	880	0	360	300	0	700	0	160	210	4985	4636
1 and 2																		
(a) Total Division sessions held	19	8	2	2	5	9	5	9	0	6	6	6	7	3	2	5	94	93
(b) Total Division papers presented	54	16	4	5	11	19	10	20	0	19	25	10	29	6	3	15	246	243
3 *Research*																		
(a) Survey Committee at work	0	0	1	1	0	0	0	1	0	1	1	0	1	1	1	0	8	8
(b) Executive Committee acting as Survey	1	1	0	0	1	1	1	0	1	0	0	1	0	0	0	1	8	8
(c) Projects being developed at present	0	2	0	0	3	0	1	2	0	0	5	0	0	0	0	0	13	4
(d) Special Research Committee authorized during year at work	1	1	0	0	1	0	1	0	0	1	1	0	0	0	0	2	8	5
4 *Progress Reports*	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	14	14
5 *Enrolment in Divisions, 1929*	2300	3600	3768	2000	2750	4075	6325	2550	*	3050	1250	3942	350	1200	550	710		38,410
6 *Enrolment in Divisions, 1930*	2575	3803	3818	2015	2250	3951	6255	2608	*	3084	1354	4033	363	1250	609	727	38,695	

[1] Includes Akron, Detroit, and Annual Meetings.
[2] Includes more than one meeting of the Division: [2a] National Meeting, Dayton, May, 1930; Pittsburgh Meeting, Feb., 1930; Seattle Meeting, May, 1930; Chicago Meeting, Aug., 1930; [2b] and [2c] National Meetings were held with Management Congress; [2d] National Meeting, Pittsburgh, Nov., 1929; New York Meeting, April, 1930.
[3] Fuels National Meeting transferred from October to February so as to hold it during Midwest Power Conference in Chicago.
* All members are registered in National Defense Division.
Note: Table does not include any meetings held after October 8, 1930.

similar cooperative program is being arranged for Cleveland next April with other societies interested in management. These two Divisions also have done excellent work in some of their subcommittees. The Waste Elimination Committee of the Management Division has attracted considerable attention, both in this country and abroad, and its work promises to be of increasing value. The Materials Handling Division, during the past year, formed a subcommittee of representatives of materials-handling equipment manufacturers to get concerted action on a number of vital problems in the field. The response of industry has been splendid, and a constructive program has been outlined for the coming year.

The Applied Mechanics Division is the youngest and one of the best organized. It is handling its highly technical field in an admirable fashion. During the past year it has cooperated actively in the International Congress of Applied Mechanics in Stockholm, and with the consent of Council has invited and urged that the next International Congress of Applied Mechanics be held in this country in 1938.

The Aeronautics Division, besides holding its National meeting at Dayton, Ohio, held several meetings jointly with Local Sections. One of these was held at the University of Washington under the auspices of the Western Washington Section late in May, and enabled a fine technical meeting to be held on the Pacific Coast due to the close cooperation between the Division and the Western Washington Section. Other similar joint meetings were held in Pittsburgh in March, and Chicago in August.

In cooperation with Pennsylvania State College, the Oil and Gas Power Division held another strikingly successful meeting on the college campus last June.

Attention might be called again to the splendid work that is being done by the smaller Divisions of the Society which have a large and fertile field for future growth. The following Divisions have been actively covering their fields and are gradually winning support and attention from the industries in their fields: Railroad Division, Wood Industries Division, Textile Division, and Printing Industries Division.

The Fuels, Power, and Hydraulic Divisions have been equally alert in bringing out the developments in their fields. The Fuels Division plans a National Meeting next February at the time of the Midwest Power Conference and Exposition. The Hydraulic Division is securing support for translation of important foreign hydraulic papers. Its Survey Committee prepared and issued a digest of foreign hydraulic literature particularly relating to research which is believed to be of considerable value and importance. Its Subcommittee on Standardization of Shaft Couplings has completed a set of standard dimensions for the standardization of this feature of hydroelectric units. This subcommittee had the benefit of conferences with turbine and generator manufacturers which brought about an early agreement leading to the actual use of the proposed standard dimensions by the industry.

Future Development

From the preceding brief review of the Divisions' activities for the year and the accompanying tabulation it is evident that the Divisions are functioning satisfactorily. However, the Divisions cannot have their fullest possible development without increased financial support to take care of their further growth. Each of the Divisions functions now with volunteer committeemen, who give a great deal of their own personal time and attention to Division work. They have to pay their own expenses to the national meetings of the Divisions, there being no funds to care for traveling expenses. Each Division has anywhere from five to twelve trade organizations and societies with which it must keep in touch, and in time this can be properly done only by having a part-time paid secretary for each Division.

Also, some of our Divisions (Iron and Steel, Materials Handling, Aeronautics, Printing Industries, Textile, Wood Industries, etc.), have found that they must have more of the technical men in their field as members of the Society or at least have them kept informed of what the Society is doing. To accomplish this, many of the Divisions have been extensively inviting non-members to attend their meetings in order to bring them in touch with what we are doing and to increase our usefulness to industry.

To take care of these growing Divisional needs it would seem that some method could be devised whereby the Divisions may bring into the Society greater revenue and in turn have more for their own growth. Such a method could possibly be devised as part of our publication policy. Our Divisions are responsible for the most of the technical material that is published, so that if they can increase its use and sale they should be allowed to profit more directly by the increased revenue. The Standing Committee on Professional Divisions is now discussing the matter with the Publications Committee in expectation of developing some plan.

Respectfully submitted,

J. W. Roe, *Chairman*
H. W. Brooks
W. F. Dixon
P. T. Sowden
C. B. Peck
R. T. Kent
Archibald Black, *Ex-Officio.*

LOCAL SECTIONS

A total of seventy-one Local Sections of the Society has now been authorized and are functioning in thirty-eight States of the Union. The territories of these Sections vary in size from a minimum radius of thirty miles from the City Hall of the headquarters city to that of the Mid-Continent Section embracing several states and parts of states. To the majority of members living in these respective communities or groups of communities the Society is encompassed in the activities of the Local Sections—aside from the receipt of its literature the Section is the Society.

It cannot be questioned that the present large membership of the Society is due principally to its geographical development through the Local Sections. The upward trend of the membership is chronologically coincident with the first meetings of the Society in geographical districts in 1909. When these geographical groups began in 1915 really to function to a degree that warranted the Council in appointing a Standing Committee to administer their activities, an even greater rate of increase of membership development occurred. The membership increase in the territory of the last authorized Section, St. Joseph Valley, shows that whereas there were 39 members at the time of organization on December first, there were on April first, fifty-one members, an increase of 31 per cent within a period of only four months.

Prospective Norwich Section

For some months active interest has been taken in the development of proper conditions under which a Section may be authorized in Eastern Connecticut with headquarters at Norwich, Conn. Mr. William Buck, of Jewett City, Conn., planned an organization meeting on October 29. A number of applications for membership are pending from this district. The territory will include Bradford and Westerly, R. I.

Meetings

The meetings of the Local Sections have a wide range in character. In addition to those held locally there are included meetings of national character where the Local Section provides all of the social portion of the programs for Semi-Annual Meetings, Regional Meetings, and also for meetings of the Professional Divisions. A large part of the success of the latter group has been dependent upon the organization of the Local Sections to provide necessary meeting places and personnel to handle local arrangements and to produce attendance. Continued cooperation with Professional Divisions is evident by the National Divisional Meetings which were held as listed herewith, the Local Section assisting in each case.

Cleveland	Machine Shop Practice	October 1–2, 1929
Philadelphia	Fuels	October 7–10, 1929
Rock River Valley	Wood Industries	October 16–18, 1929
Pittsburgh	Printing Industries	November 7–8, 1929
Chicago	Machine Shop Practice	March 3–5, 1930
Chicago	Materials Handling	March 5–7, 1930
Boston	Textile	May 2, 1930
Dayton	Aeronautic	May 19–22, 1930
Central Pennsylvania	Oil and Gas Power	June 12–14, 1930
Chicago	Machine Shop Practice	September 22–24, 1930
Chicago	Iron and Steel	September 24–26, 1930

While the main objective of the Local Sections meetings is not to produce papers of fundamental technical importance, nevertheless a considerable number of the papers appearing in the publications of the Society during the last fifteen years originated at Local Sections meetings.

Whereas attendance figures are not usually reported, and occasionally, for one reason or another, a Local Section meeting has not been reported to Headquarters, there is a record over the past five

years of 1815 meetings held by the existing Sections detailed by years as follows:

1925-1926	387
1926-1927	328
1927-1928	367
1928-1929	406
1929-1930	327
	1815

The number of meetings held by Sections during 1929-1930 is shown in the accompanying chart (Table 1). This chart also details the membership of the respective Sections on October 1, 1929, and October 1, 1930, the net increase, the percentage of membership increase, and the fact that ninety per cent of the entire membership is now residing within the territory of established Local Sections.

Scope of Service

The service of the Local Sections covers a very wide variety of activities. The most recent call made upon them has been to assist in the study of the Economic Status of the Engineer, and the response by the membership to a questionnaire relative thereto. Last fall they were asked in a number of instances to entertain prominent foreign engineers traveling through the United States en route to the World Engineering Congress in Japan. Frequently, they are called upon individually to provide details regarding the records and availability of a certain local engineer who is being considered for service on a governmental or Society committee or perhaps for employment or consultation service. They frequently serve in a wide variety of civic engineering developments either for their municipality or State or for the nation. They have contributed on several occasions to the entertainment of groups of members traveling to meetings at distant points. They have cooperated in furthering the activities of the Standardization and Research Committees, such as the adoption of the standard on fire-hose couplings. They have participated in campaigns on "Smoke Abatement." They have reviewed tentative reports issued by various committees which are disseminated through the Local Sections with the request that they be referred to a committee of experts in the local groups for study and report back to the National Committee. Also, they have made a study of local conditions pertinent to the laws or desirability for laws on Licensing and Registration of Engineers.

Transportation and Tours

Because of its geographical associations, the Committee on Local Sections was selected as the logical committee to administer the handling of the transportation of the Society, including the arrangement and conduct of the special tours in connection with the Fiftieth Anniversary Meeting of the Society. Two such tours were planned, tentatively arranged for, and given wide publicity, but there was not sufficient response to warrant going ahead with them. Arrangements were completed and carried out for special trains between New York and Washington. The handling of these travel arrangements obviously has developed a quantity of reliable data and connections which is available at all times not only to the officers of the Society, but to the individual members, many of whom have availed themselves thereof.

Reduced fares to Annual, Semi-Annual, and other national meetings are arranged under the supervision of the Committee and result in the saving annually of thousands of dollars on the part of members attending these meetings.

Elimination of Waste

Fourteen Local Sections arranged meetings this year on the matter of "Elimination of Waste," and a number of them also encouraged the organization of individual plant programs to accomplish this purpose. A total of 439 companies were sent literature.

Foreign Relations

The Committee on Local Sections has been responsible during the last few years for the development of an activity which has been carried on for several years by the Secretary, and which has been called recently by the term, Foreign Relations. Because so many of the contacts of the Society are developed through Local Sections, and because so many of the services rendered to foreign engineers are accomplished through the medium of the Local Sections, it has seemed logical for this Committee to undertake to cooperate with the Secretary in this highly important function of the Society.

In order better to serve the large number of engineers from other countries who visit the United States, either individually or in groups, a number of the larger industrial concerns have been negotiated with as to their willingness to entertain foreign visitors, or even American engineers, who might be interested in being shown through the respective plants. A very encouraging response has been received and relatively few concerns have been unwilling to cooperate. As a result, a system has been developed which simplifies the procedure in making the necessary arrangements, and also in giving adequate travel directions to those making the visits. In the matter of tours of any extent, it has been found that the Local Sections have been most willing to receive the visitors and frequently arrange to entertain them.

Another phase of Foreign Relations work which has been carried on over a period of several summers and was continued during the past year, has been making arrangements whereby recent graduates of engineering colleges who come to this country from England, and occasionally from other countries, are given the opportunity to visit

TABLE 1 MEMBERSHIP IN LOCAL SECTIONS, OCTOBER 1, 1930

Section	Membership Oct. 1, 1929	Membership Oct. 1, 1930	Increase	Per cent	Meetings 10/29–10/30
Akron	139	163	24	17.3	5
Anthracite Lehigh Valley[1]	341	334	−7	−2.0	9
Atlanta	110	113	3	2.7	7
Baltimore	195	225	30	15.4	8
Birmingham[1]	109	99	−10	−9.2	5
Boston	767	780	13	1.7	8
Bridgeport	174	200	26	14.9	9
Buffalo	229	244	15	6.5	3
Central Pa.[1]	118	113	−5	−4.2	1
Charlotte[1]	46	43	−3	−6.5	4
Chattanooga[1]	26	24	−2	−7.7	1
Chicago	1139	1145	6	0.5	9
Cincinnati	330	343	13	3.9	6
Cleveland	421	435	14	3.3	5
Colorado[1]	100	96	−4	−4.0	10
Columbus	83	85	2	2.4	2
Dayton[1]	103	102	−1	−1.0	3
Detroit	534	554	20	3.8	8
Erie	90	95	5	5.6	2
Florida	68	68	..	....	2
Green Mountain	46	48	2	4.4	2
Greenville[1]	33	31	−2	−6.1	2
Hartford[1]	154	151	−3	−1.9	7
Houston	140	144	4	2.9	5
Indianapolis	141	147	6	4.2	5
Inland Empire	23	25	2	8.7	5
Kansas City	132	136	4	3.0	7
Knoxville[1]	50	49	−1	−2.0	5
Los Angeles	428	445	17	4.0	5
Louisville[1]	47	44	−3	−6.4	5
Memphis	28	28	..	....	2
Meriden[1]	35	34	−1	−2.9	2
Metropolitan[1]	5046	4925	−121	−2.4	25
Mid-Continent	161	167	6	3.7	1
Milwaukee	292	298	6	2.1	6
Minneapolis	69	74	5	7.3	2
Nebraska	30	34	4	13.3	2
New Britain	53	53	..	....	6
New Haven[1]	147	145	−2	−1.4	6
New Orleans	89	90	1	1.1	2
North Texas[1]	72	69	−3	−4.2	3
Ontario	143	163	20	14.0	8
Oregon	70	75	5	7.1	7
Peninsula[1]	84	80	−4	−4.8	1
Philadelphia	1274	1316	42	3.3	9
Pittsburgh	580	611	31	5.3	0
Plainfield	314	320	6	1.9	5
Providence	199	200	1	0.5	7
Raleigh[1]	31	30	−1	−3.2	4
Rock River Valley	74	84	10	13.5	3
Rochester	135	138	3	2.2	2
St. Joseph Valley[2]	..	61	61	....	2
St. Louis	293	308	15	5.1	2
St. Paul	51	52	1	1.9	3
San Francisco	397	423	26	6.5	6
Savannah[1]	22	20	−2	−9.1	4
Schenectady	205	234	29	14.4	2
Susquehanna	62	70	8	12.9	3
Syracuse[1]	142	126	−16	−11.3	6
Toledo	86	95	9	10.5	5
Tri-Cities[1]	79	76	−3	−3.8	4
Utah[1]	44	37	−7	−15.9	5
Utica	30	35	5	16.7	0
Virginia	143	183	40	28.0	2
Washington, D. C.	181	200	19	10.5	5
Waterbury[1]	98	92	−6	−6.1	3
West. Mass.[1]	156	145	−11	−7.1	2
Western Washington	116	116	..	....	5
West Virginia	54	66	12	22.3	0
Worcester	194	197	3	1.6	9
Youngstown[1]	110	84	−26	−23.6	1
	17,704	18,035	331	1.8	327

[1] Loss in membership.
[2] New Section, Dec. 2, 1929.

Total membership in Society, Oct. 1, 1929, 19,421; Oct. 1, 1930, 20,016; 2.9 per cent gain. 90.1 per cent of membership in Local Sections. Total number of Student Branches, 105.

plants in the vicinity of New York during the few days when the vessels upon which they were sailing are in port.

Again, in a number of instances there are engineers of foreign countries, particularly of Germany, who come here regularly for a two-year period, during which they become familiar with American industrial conditions either through special courses in American technical colleges or through practical application in the various industries. Approximately one hundred German students visit the United States annually, and our Society has been instrumental in arranging their placements. A system has been devised whereby the Society keeps a record of the credentials of all persons introduced so that responsibility has been avoided for interlopers of any sort.

As a result, the Society's good-will in foreign countries has been broadened so that when American engineers desire to visit these countries, the Society is able to have opened to them certain plants and opportunities which were closed but a few years ago. Incidentally, there are increasing calls from foreign concerns for the services of American engineers, and this has helped to develop another interest of the Committee on Local Sections, namely, the Employment Service.

Employment

It has been deemed advisable to place under the supervision of the Committee on Local Sections the general direction of the Employment Service because of its geographical development. Offices have been established in Chicago and San Francisco to supplement the services rendered for some years past from New York. Other sections of the country are inquiring as to the wisdom of having additional offices opened in their territories. Inasmuch as the type of organization developed by the National Board of the Employment Service has provided that in each of the cities where offices are conducted, the local Advisory Committee be made up of one member representing each of the four Societies, and as the Local Sections in Chicago and San Francisco have selected the A.S.M.E. representatives, the activity has, to a certain extent, been under the direction of Local Sections.

The Employment Service is one which should promptly be made one of the outstanding features of the Society's activities. To a degree this has already been recognized by the Council in its having provided a committee to study the economic status of the engineer. The work of that Committee will be affected to a considerable extent by the employment or non-employment of the engineering professions as represented by the members of our own Society. The Employment Service, in order to take advantage of that phase of the developments of the Committee on the Economic Status of the Engineer, has made it possible for one of its staff to give part time to serve the Committee on the Economic Status in carrying on its investigation.

The employment activity has but recently come into the category of the responsibilities of the Local Sections Committee and it will be the aim of the Committee to develop the Service and extend its usefulness.

Mid-Western Field Office

The increasing and constantly widening scope of Society activities in the mid-western area have added to the expense and difficulty from year to year to contact properly with Sections and Student Branches of the Middle West, and therefore, upon the recommendation of the Committee on Local Sections, the Council authorized last year the development of mid-western headquarters at Chicago and the appointment of a mid-western field secretary. Several Sections in recent years have recommended that more attention be paid by the headquarters staff to their individual needs. In the sixteen mid-western states, twenty-six Local Sections and thirty Student Branches are active, and since the mid-western office was established at Chicago in October, 1929, another Section has been formed, designated the "St. Joseph Valley Section," with headquarters at South Bend, Ind.

Inasmuch as the Society already had a lease on an office in the Engineering Building in Chicago, only partially used by the Advertising Department, the Committee decided upon joint occupancy of the office with a stenographic assistant at that point in lieu of an assistant in the New York office. Therefore it was possible to add to the efficiency of the Chicago Advertising Office as well as to provide better and more prompt service to the Mid-Western Sections and Student Branches. In order to conduct this work without impairing the efficiency of the existing organization in the East, Mr. R. R. Leonard was promoted from the Publications Department to serve as Mid-West Field Secretary.

A large part of the efforts during the first year in the building up of this mid-western office has had to do with educational methods as far as the officers of the Local Sections and Student Branches were concerned so that they would learn to communicate with Chicago instead of New York, and they have been highly pleased with the results. The new system is effecting economies, helping in emergencies, and providing the kind of service which warrants increased devotion on the part of the many members of the Society who give unselfishly of their services to the many Committees administering the work of the Local Sections and Student Branches of this great mid-western industrial area.

Statement of Petroleum Activities in the Mid-Continent Section

On November 2, 1929, a telegram was sent to the Society headquarters by the Secretary of the Mid-Continent Section, requesting an immediate visit by an officer of the Society to discuss necessary procedure to obtain adequate activity by the Society on matters pertinent to the promotion of petroleum progress from the mechanical engineer's viewpoint. In response thereto, a conference was held on November 5 at Tulsa, and as a result thereof it was arranged to have representatives of the Mid-Continent Section and Petroleum Division present their proposed projects to Council and the interested Standing Committees of the Society during the course of the 1929 Annual Meeting. As a result it was decided to have Assistant Secretary Ernest Hartford visit Tulsa in January, 1930, for the purpose of assisting in the further development of the proposition and to arrange a program of activities to transpire in March, 1930, when members of Council and the Committee on Local Sections would meet at Tulsa for further consideration of the matter. During the month of January a number of technical committees were organized in the Mid-Continent area to work on various mechanical engineering problems concerned with the petroleum industry. More than one hundred and twenty men were appointed on these various committees, which undertook activities concerned with production of petroleum and its transportation, and also the very important matter of unfired-pressure vessels, of which such a large number are used in the petroleum industry. The Committee on Production decided that the most important problem needing development was prime movers for rotary drilling. Subcommittees were organized to handle the four phases of this problem—electricity, gas engines, oil engines, and steam. A Committee on Gas Transportation to study the various projects of mechanical engineering character which require development decided the first activity to engage its attention would be a study of compressors. The phase of transportation having to do with crude oil concerned itself with the development of an automatic pipe line pumping station which was designed by the Committee and constructed on the grounds of the International Petroleum Exposition. A second committee concerned itself with a study of the fixed and operating charges for motor-driven oil-pipe-line pumping stations. A Committee on Unfired Pressure Vessels undertook the study of the Unfired Pressure Vessel Section of the A.S.M.E. Boiler Construction Code, and is cooperating with the special committee of the Society engaged in the study of that problem so that it will provide adequately for the construction of vessels of this type which are used so extensively in petroleum practice.

March 9 to 12 brought to Tulsa seven members of Council and Secretary Rice, and five members of the Committee on Local Sections. This group was taken one day to visit several plants showing current practice in pumping stations both for natural gas and oil. Another day was devoted to a visit to the Oklahoma City field where the officers of the Society were accorded every facility to become familiar with intricacies of oil-field practice. They had opportunity to witness deep-well drilling with different types of prime movers by the rotary process. They saw large quantities of steam exhausting into the air, wasteful methods of using water, and inefficient use of gas and oil in the production of heat. They saw various phases of refining and in this way got some conception of the mechanical engineering problems of the petroleum industry with its investments of upward of twelve billions of dollars and engaging over one million and a quarter of people. They met with a number of leaders of the industry—both executives and technicians. These included such outstanding characters in the industry as Wm. G. Skelly, President of The Skelly Oil Company, and President of the International Petroleum Exposition; R. S. Knappen, Vice-President of the Gypsy Oil Company; Dr. John D. Finlayson, Chancellor of the University of Tulsa; Wm. B. Holden, Executive Vice-President of Tulsa Chamber of Commerce; Thomas R. Weymouth, Chairman of the Board of the Oklahoma National Gas Company; Wm. G. Heltzel, Chairman of the Petroleum Division of the A.S.M.E.; Mr. Pat. Murphy, Commissioner of Labor of the State of Oklahoma; David L. Trax, Consulting Engineer of Gypsy Oil Company; and Raymond Carr, Petroleum Engineer of the Sinclair Oil & Gas Co.; as well as the engineers of a number of manufactories of oil-country equipment of producing oil companies, and of public utilities serving the industry.

The result of the large amount of information derived by the officers

of the Society at this conference was the formulation of a program which was adopted at the Detroit meeting of Council, and which provided a special appropriation of $1500 to care for the necessary staff and traveling expenses between the 15th of June and 1st of October. The action taken by Council for the organization to handle the petroleum problem was as follows:

(*A*) That the responsibility for the professional activities of the A.S.M.E. in the petroleum field should be concentrated.

(*B*) That this responsibility should rest with the Petroleum Division.

(*C*) That the Petroleum Division, with the Mid-Continent Section through its representatives as provided below, shall recommend to the President an Advisory Committee, to be appointed by Council, or its Executive Committee, which shall have direct access to Council, for recommendations. This Advisory Committee may contain representatives of other Standing Committees of the Society, technical and industrial leaders of the petroleum industry, and other organizations and industries interested. This Advisory Committee shall be appointed annually so long as the need exists.

The Advisory Committee should:

(1) Advise the Petroleum Division Executive Committee in the formulation and execution of its program of activities

(2) Aid in securing cooperation of other bodies, and

(3) Help in coordinating the program with those of other agencies of the Society and outside.

(*D*) That the Chairman of the Mid-Continent Section shall be an ex-officio member of the Petroleum Division Executive Committee with vote. A working majority of the Petroleum Division Executive Committee shall for the present be from the Mid-Continent Section.

(*E*) That in endorsing this report, the above action does not supplant the existing organization of the Mid-Continent Local Section. The Chairman of the Mid-Continent Section continues to be the executive in charge of its activities in that territory.

(*F*) *Personnel of Petroleum Division*

It was agreed that the Petroleum Division Executive Committee be asked to canvass its personnel and make suitable recommendations to cover "*D*" above.

(*G*) *Staff and Financing*

(1) Staff support as to persons and times shall be in the hands of Calvin W. Rice, Secretary

(2) In view of the emergency which exists, expenses and clerical help needed in Tulsa and by the Petroleum Division up to October 1, 1930, be carried by a special contingency appropriation not to exceed $1500.00, as authorized at this time

(3) The recognized Petroleum Division is to outline a program and submit a budget for its activity October 1, 1930–1931, for consideration by Council at its October meeting.

As a result of this action, Assistant Secretary Hartford returned to the Mid-Continent Area and after developing certain committee work, negotiated with Professor Wm. H. Carson, Head of the Department of Engineering at the University of Oklahoma, to devote his full time during summer vacation season to maintain committee activities and particularly to direct a field test on a steam rotary-drill rig. This being the first time any such test had ever been undertaken, it was necessary to assemble certain types of recording apparatus heretofore unused in the oil fields. Certain portions of the apparatus had to be designed and constructed for the proposition. After overcoming many obstacles, the necessary apparatus was assembled to the equipment of a contractor on an Indian Territory illuminating oil company's well which started drilling in the Oklahoma City field the last week of September. Specific data are being recorded on a twenty-four hour per day basis with regard to the fuel consumption, water consumption, steam generated and used, and efficiency of slush pumps and other mechanical apparatus so that upon completion of the drilling of the well there will be available for the first time a definite knowledge of these various phases of operation. It is the plan of the Committee that these data shall be studied sufficiently to make apparent any deficiencies which might exist. Incidentally, certain of the apparatus, such as the engines being used on the job, will be taken to the laboratory of the University of Oklahoma and subjected to a laboratory test, which in turn will give comparable data which can be utilized in connection with the figures obtained from the practical operating test. The Committee will then consider the wisdom of undertaking to design what might be termed a theoretical project, a steam drilling rig, and if the progress warrants so doing, will undertake to persuade a group of oil-producing companies to have such apparatus outlined, built, and used in drilling in the well, subject also to another test which will record actual operating conditions in the same way as is now being done with the standard steam drill rig. After the theoretical calculations thereof are justified, it is probable that the final result of the activities of this Committee will be to revolutionize the present rotary drilling methods.

At this point credit should be given for the very generous and complete cooperation of the Engineering School and particularly the Department of Mechanical Engineering of the University of Oklahoma.

While these several committees were carrying on the projects outlined in the foregoing paragraphs, another group was actively engaged in developing a program of technical papers for presentation at the First National Meeting of the Petroleum Division of the A.S.M.E., which was held in the auditorium on the grounds of the International Petroleum Exposition during the seventh renewal of that stupendous demonstration of apparatus used by the petroleum industry. Twenty-five papers of unusual value and interest were prepared and presented in the A.S.M.E. issue of a special publication designated as *Petroleum Mechanical Engineering*, which contained the preprints of these papers together with a large volume of advertising. The success of this publication was such that it has encouraged the expectation that it will be made a regular semi-annual publication of the Society.

The automatic pipe-line station proved to be an outstanding feature of the Petroleum Exposition, with its uncanny functioning, especially through its remote-control station and apparatus whereby it was operated theoretically at a distance of fifty miles over telephone wires. Such demonstrations were recorded as the shutting down of the plant due to a hot bearing, the reversal of the pumps due to a break in the line and the sucking back into the station's supply tanks of the oil in the pipes between the station and the point at which the break occurred; and the more than human functioning of the apparatus whereby when all valves were set diametrically opposite to their accustomed position and the current was turned on they automatically rectified themselves and proceeded to operate.

Program for Ensuing Year. In order to guard against any duplication of effort or overlapping of activities conducted by other organizations carrying on similar activities, it was deemed advisable to invite major executives of the various branches of the petroleum industry to serve on an Advisory Board of the Petroleum Division of the A.S.M.E. This Board, which has been officially appointed by the Council of the A.S.M.E., comprises the following personnel, and will be added to from time to time as conditions warrant and opportunities present themselves:

Oil Pipe Line Transportation

Burton E. Hull, Houston, President, Texas Pipe Line Company.
H. S. Austin, Tulsa, President, Ajax Pipe Line Company.
J. R. Manion, Tulsa, President, Sinclair Pipe Line Company.

Production

Kendall Winship, Tulsa, Vice-President, Gypsy Oil Company.
A. W. Peek, Chicago, Director, Standard Oil of Indiana.

Refineries

Walter Miller, Ponca City, Vice-President, Refineries, Continental Oil Company.

Gasoline

F. E. Rice, Bartlesville, Vice-President, Phillips Petroleum Company.
S. G. Sanderson, Tulsa, General Superintendent Gypsy Oil Company.

Gas Transportation

E. F. Schmidt, Dallas, General Superintendent, Lone Star Gas Company.
T. R. Weymouth, Tulsa, President, Oklahoma Natural Gas Company.

Schools and Colleges

J. H. Felgar, Norman, Dean, University of Oklahoma.
W. H. Gladson, Fayetteville, Dean, University of Arkansas.
P. S. Donnell, Stillwater, Dean, Oklahoma A. & M. College.
R. L. Langenheim, Tulsa, Dean, University of Tulsa.
N. A. C. Smith, Bartlesville, U. S. Bureau of Mines.

This group met in Tulsa on Friday, October 3, and elected J. R. Manion as the permanent chairman. At that meeting it also endorsed the following:

Projects for Petroleum Division, A.S.M.E., 1930–1931. Through the new Tulsa Secretary, it is planned to assemble all available me-

chanical engineering data pertaining to the oil and gas industry and to prepare a bibliography of this to eliminate duplication by our own or other organizations.

(A) Boiler Code and Fluid Meters Committees

(1) Cooperation with A.S.M.E. Main Boiler Code Committee to assist them in keeping in touch with oil-field conditions and requirements.

(2) Continuation of Subcommittee on Unfired Pressure Vessels for use in field practice in riveted construction, welded construction, and combinations of riveted and welded construction.

(3) A.S.M.E. formed a National Fluid Meters Committee in 1916 to develop the theory of fluid meters of all kinds and to report on the best methods of their application. Reports have been issued which do not include the theory or practice of equipment generally used in oil and gas work. Progress was made last year when this Committee met with the Southwestern Meter School at Norman, Oklahoma. It is recommended that the Petroleum Division negotiate with the Fluid Meters Committee to appoint a subcommittee to care for the problems of the oil and gas industry.

(B) Oil Pipe Line Transportation

(1) Continuation of Automatic Pumping Station as a "proving ground" for equipment and apparatus as developed by various manufacturers. Development of "Uniform Code for Economic Analysis of Different Types of Oil Pipe Line Pumping Stations."

(2) Experiments on temperature loss in pipe lines, carrying hot oil of high viscosity.

(3) Assembling data to be incorporated in hand-book containing all useful information for oil-pipe-line men.

(C) Production

(1) Prime Movers for Rotary Drilling—(*a*) Steam: Running of test in Oklahoma City field and correlating and compiling data resulting therefrom, with report; (*b*) Electricity: Preparation of report from available data; (*c*) Gas Engine: Preparation of report from available data; (*d*) Oil Engine: Preparation of report from available data.

(2) Study of various reports and comparison thereof, with possible recommendation of theoretically ideal set-up of apparatus to improve the efficiencies and economies of rotary drilling under given conditions. This possibly to be followed by the actual assembling of an ideal "steam" or other prime mover rig, and the drilling of a practical well with another test run under practically same conditions as to set-up of test apparatus as is being followed now, thereby getting a result which will definitely prove the practical value of the theoretically ideal rig.

(D) Refineries

(1) Proposed Research Program on Heat Transfer Apparatus—(*a*) Vapor to Liquid Exchanger Problem: To determine factors influencing heat exchange values in condensing hydrocarbon vapors (such as mixtures of hydrocarbon vapors and steam, mixtures of hydrocarbon vapors and non-condensible gases) in vapor to liquid heat exchangers including pressure drops; (*b*) Liquid to Liquid Exchanger Problem: To determine factors influencing heat exchange values of the liquid flowing outside the tube bundle, including effect of non-condensible gases on liquid to liquid exchangers, including pressure drops.

(2) Fractionation and bubble-tower efficiencies.

(3) The termination of convection coefficients in furnaces.

(4) The effect of non-condensible gas on heat-transfer coefficients with pure hydrocarbon vapors or approximating a composition of naphtha and refined oils.

(5) An accurate pressure-drop formula for hydrocarbon mixtures flowing through tubes as in furnaces and determining accurately proper correction where a variable amount of vaporization takes place.

(6) Improving efficiencies of high-pressure hot-oil pumps.

(E) Gas Transportation

(1) Economic design of pipe line company stations—(*a*) Proper method of measuring volume of gas discharges by compressors; (*b*) Proper ratings and capacities of compressors.

(2) Economic design of drips from main lines.

(3) Complete investigation of gate valves with the plan of making suitable code.

Projects for Future Consideration. (1) Correct design of mud slush pumps. (In many cases drillers run at such high rates of speed that they do not get the full efficiency of the pump.)

(2) Transmission: The method of pumping wells is practically the same today as it was ten years ago, i.e., by the use of the walking beam and belt connections to the bull wheel. The A.S.M.E. could organize groups of engineers in an effort to develop improved methods for pumping deep wells.

(3) Specifications of gate valves (with a safety factor sufficient but not too high to be accepted by the petroleum industry).

(4) Development of hypothetical rotary hook-up for Diesel and other internal-combustion engines to prove the feasibility of these in future drilling activities due to the low cost of power developed. (Several Diesel engine manufacturers' representatives of Tulsa have stated their willingness to cooperate with the A.S.M.E. in developing suitable hook-ups for Diesel engines and rotary equipment.)

Personnel Identified With Petroleum Activities. Subsequently, at its meeting at French Lick, the A.S.M.E. Council approved of the foregoing recommendations and also voted an appropriation of funds necessary to employ a regular secretary to care for the petroleum activities of the Society in the Mid-Continent territory. With the consent of the Dean of Engineering of the University of Tulsa, Professor Edward Anderson, a full member of the A.S.M.E. for several years and now Associate Professor of Petroleum Engineering at the University of Tulsa, has consented to serve in this secretarial capacity and arrangements have been completed whereby he will have his office in the Tulsa Building, where he will have the assistance and cooperation of the Tulsa Chamber of Commerce. Present plans predict the actual opening of this office on November 15, after which date meetings of the various committees will be held regularly in this office and interested executives and engineers of the industry will be encouraged to call for any assistance that it may be possible for the A.S.M.E. to render.

TABLE 2 LOCAL SECTIONS VISITED BY MEMBERS OF THE COMMITTEE ON LOCAL SECTIONS, 1929–1930

Section	T. L. Wilkinson, Chairman	H. R. Westcott	C. W. Bennett	J. M. Todd	J. W. Haney	E. Hartford, Secretary
Akron	.....	.....	.....	.....	.....	Oct. 1929
Birmingham	.....	Mar. 1930	.....	Mar. 1930	.....	.....
Bridgeport	.....	.....	.....	.....	.....	Nov. 1929
Chattanooga	.....	Mar. 1930	.....	Mar. 1930	.....	Jan. 1930
Chicago (Midwest Office)	.....	.....	.....	.....	.....	Oct. 1929, Feb., Apr., June, Sept. 1930
Detroit	June 1930	June 1930	June 1930	June 1930	June 1930	Feb., June 1930
Erie	.....	Mar. 1930	.....	.....	.....	.....
Hartford	.....	Oct. 1929	.....	.....	.....	.....
Houston	.....	.....	.....	Mar. 1930	.....	.....
Indianapolis	.....	.....	.....	.....	.....	Oct. 1929
Kansas City	Mar. 1930	.....	.....	.....	Mar. 1930	.....
Knoxville	.....	Mar. 1930	.....	.....	.....	.....
Memphis	.....	Mar. 1930	.....	Mar. 1930	.....	Jan. 1930
Metropolitan	Dec. 1929	Dec. 1929	Dec. 1929	Dec. 1929	.....	(Resident)
Mid-Continent	Mar. 1930	Mar. 1930	Mar. 1930	Mar. 1930	Mar. 1930	Nov. 1929, Jan., Mar., June, Sept., Oct. 1930
Milwaukee	.....	.....	.....	.....	.....	Oct. 1929
Nebraska	.....	.....	.....	.....	(Resident)	.....
New Haven	.....	(Resident)	.....	.....	.....	.....
New Orleans	.....	.....	.....	(Resident)	.....	.....
North Texas	.....	.....	.....	Mar. 1930	.....	.....
Peninsula	.....	.....	.....	.....	.....	Mar. 1930
Philadelphia	.....	.....	.....	.....	.....	Jan. 1930
Pittsburgh	.....	.....	(Resident)	.....	.....	.....
St. Joseph Valley	.....	.....	.....	.....	.....	Feb. 1930
St. Louis	Mar. 1930	Mar. 1930	.....	.....	Mar. 1930	Oct. 1929
Tri-Cities	(Resident)	.....	.....	.....	.....	Jan., Apr. 1930
Washington, D. C.	Apr. 1930	Apr. 1930	.....	.....	.....	Apr. 1930

The Executive Committee of the Petroleum Division in general charge of all activities of the Division is comprised of the following:

W. G. Heltzel, *Chairman*
H. J. Masson, *Secretary*
W. H. Carson, *Western Secretary*
H. R. Pierce
J. W. Hays
Walter Samans
E. H. Barlow.

The Executive Committee of the Mid-Continent Section of the A.S.M.E. which is closely identified with this whole program has the following personnel:

A. J. Kerr, *Chairman*
H. W. Manley, *Secretary-Treasurer*
B. P. Sibole, *Vice-Chairman*
M. H. Kotzebue
F. S. Kelly
R. W. Curran.

Student Branches and Local Sections

Members of Student Branches have been encouraged during the past year to attend Local Section Meetings and the following Sections arranged meetings which would be of special interest to bring about cooperation.

Student Branch	Section	Date of Meeting
California Institute of Technology	Los Angeles	Feb. 19
Clemson College	Greenville	May 13
Drexel Institute	Philadelphia	Feb. 25
University of Florida	Florida	Nov. 18
State University of Iowa	Tri-Cities	Nov. 13
University of Kansas	Kansas City	Nov. 20
Northeastern University	Boston	Mar. 21
Lowell Textile Institute	Boston	Mar. 21
University of Minnesota	St. Paul	Nov. 26
University of Minnesota	St. Paul	Dec. 4
University of Nebraska	Nebraska	Apr. 8
North Carolina State College	Raleigh	Feb. 25
University of North Carolina	Raleigh	Feb. 25
Oregon State Agricultural College	Oregon	May 10
Rice Institute	Houston	Mar. 22
Syracuse University	Syracuse	Mar. 20
Villanova College	Philadelphia	Oct. 7
Washington State College	Inland Empire	Nov. 2
Washington State College	Inland Empire	Jan. 24
University of Washington	Western Washington	Nov. 22
University of Washington	Western Washington	Jan. 17
University of Washington	Western Washington	Apr. 18

The Committee on Local Sections visited a number of the Sections throughout the year en route to meetings of the Society, as will be noted from the accompanying report (Table 2).

Respectfully submitted,

Thomas L. Wilkinson, *Chairman*
Harry R. Westcott
Charles W. Bennett
James M. Todd
Jiles W. Haney.

AWARDS

The Committee on Awards held a number of meetings during the year to make plans for the awards of the Fiftieth Anniversary celebration of the Society, April 5 to 9, 1930, and in connection with other awards of the Society.

The Committee assumed the responsibility of selecting the artist for the Fiftieth Anniversary Medal and of securing acceptances by ambassadors and ministers to invitations to take part in the Fiftieth Anniversary celebration.

Through the splendid cooperation of the American Engineering Council, L. W. Wallace, Executive Secretary, the Committee was able to secure acceptances and participation in the ceremonies of ambassadors and ministers representing the various countries participating who presented the engineers selected by the engineering fraternities of their particular countries for the reception of the Fiftieth Anniversary Medal.

The Committee considered a number of artists for the preparation of the Fiftieth Anniversary Medal and finally selected Julio Kilenyi of New York, N. Y.

At the request of the Gantt Medal Board and the Daniel Guggenheim Medal Board your Committee on Awards presented their medalists during the same session at which the Committee presented the recipients of the A.S.M.E. Fiftieth Anniversary Medal.

Upon the recommendation of the Committee on Awards the Council reports the following awards for 1930:

The Melville Award to H. Diederichs and W. D. Pomeroy for their paper on "The Occurrence and Elimination of Surge or Oscillating Pressures in Discharge Lines From Reciprocating Pumps."

Junior Award to Ed Sinclair Smith, Jr., of Providence, Rhode Island, for his paper on "Quantity-Rate Fluid Meters."

Student Award to Gerard Eden Claussen, of the Polytechnic Institute of Brooklyn, for his paper on "High-Temperature Oxidation of Steel," and to Harold L. Adams and Richard L. Stith, of the University of Washington, for their paper on "A Wind Tunnel for Undergraduate Laboratory Experiments."

The Charles T. Main Award to Jules Podnossoff of the Polytechnic Institute of Brooklyn for his paper on "The Value of the Safety Movement in the Industries."

During the year the Committee has recommended six loans from the Toltz Fund, amounting to $1175 leaving a balance in the Toltz Fund of $1051.82.

In Memoriam—Dr. Ira N. Hollis

"The Committee on Awards of The American Society of Mechanical Engineers records with deepest sorrow the death of its Past-Chairman, Dr. Ira Nelson Hollis. Since its inception Dr. Hollis was a member of this Committee on Awards and as chairman for much of this time he brought many valuable suggestions to the committee for action. In directing the work of the Committee in the selection of papers for awards he was helpful and effective in obtaining prompt and fair decisions. His study of the interpretation of the meaning of engineering history gave him the ability to suggest most valuable subjects of the papers submitted for the Charles T. Main Award.

"His criticism of papers submitted to the Committee for Awards was most keen and by his guidance the Committee has usually been unanimous in its decisions.

"The present method of committee procedure has been developed during his chairmanship.

"The Committee extends to the daughters and son of Dr. Hollis its sincerest sympathy during this sad period of bereavement."

Respectfully submitted,

Arthur M. Greene, Jr., *Chairman*
H. L. Seward
Roy V. Wright
K. H. Condit.

CONSTITUTION AND BY-LAWS

During the past year the Committee on Constitution and By-Laws, upon suggestion of Council, has recommended change in the wording of Article B8, Paragraph 5 of the By-Laws, to place the meetings of the Executive Committee at the call of the President and to limit the selection of members of the Executive Committee to definite officers, placing the membership at nine, five only of whom may vote.

Another important change is the proposed revision of Article C5 of the Constitution, "Fees and Dues," as recommended in the report of the Special Council Committee on Society Revenue. The report on the amendment ballot is given in the report of the Council.

This Committee has also in hand a thorough study of the By-Laws and the Rules with the object in view of eliminating repetitions and inconsistencies, and bringing into better classification the statements of the various duties of officers and committees. This is a matter of considerable weight and each Standing Committee of Council is working on it with the idea of suggestions for the final complete survey which will be made by the Committee on Constitution and By-Laws before it reports to the Council within the next year.

Respectfully submitted,

George E. Pfisterer, *Chairman*
A. D. Blake
Thomas C. McBride
R. S. Neal
H. H. Snelling.

RELATIONS WITH COLLEGES

Nine new Student Branches have been established during the year, making a total of 105 Branches—almost ten per cent more than last year. The new Branches are located at Clarkson College of Technology at Potsdam, New York; University of Detroit, Detroit,

Michigan; Michigan College of Mining and Technology, Houghton, Michigan; Missouri School of Mines and Metallurgy, Rolla, Missouri; University of North Carolina, Chapel Hill, North Carolina; North Dakota State Agricultural College, Fargo, North Dakota; University of Notre Dame, Notre Dame, Indiana; Rhode Island State College, Kingston, Rhode Island; and Texas Technological College, Lubbock, Texas.

There were 637 meetings reported, an increase of 39 meetings over last year. Greater cooperation between the Local Sections and the Student Branches is shown by the fact that there were twenty-one meetings in which both the Student Branch and the Local Section in the vicinity cooperated, while last year there were only nine. Prizes for best papers were awarded to students by the Atlanta, Louisville, New Orleans, Philadelphia, San Francisco, and Tri-Cities Sections. Both the Indianapolis and the Tri-Cities Sections have sponsored debates between two or more Student Branches.

Student Branch Conferences have been held at the Annual Meeting, the Spring Meeting, and the French Lick Regional Meeting of the Society. President Piez spoke at the most successful luncheon the Student Branches have ever held during the Annual Meeting, and the afternoon program proved very interesting and constructive.

The Committee has issued the Student Branch Bulletin monthly during the school year. This Bulletin spreads the news of the Branches and contains special articles for Student Branch officers.

Visits were made during the year by Mr. Abbott, Professor Church, Mr. Libby, Dean Prentice, Mr. Rice, Mr. Hartford, and Mr. Meyer to the following institutions: University of Arkansas, University of California, Cornell University, North Carolina State College, Ohio State University, Oklahoma A. & M. College, University of Oklahoma, Purdue University, Rensselaer Polytechnic Institute, Washington University, and Yale University.

The Committee is pleased to report that, for the first time in a number of years, every Student Branch has been active and has given us complete cooperation. Cooperation with the National Safety Council has continued and many of the Student Branches have held meetings with their liaison safety representatives as speakers.

Membership in the Student Branches has increased by almost five hundred members in the past year. The Committee calls attention to the fact that the Student Branches are the least expensive as well as one of the greatest feeders to membership in the Society, and urges that the Committee not be forced by lack of appropriation to curtail its activities to purely routine office matters.

Respectfully submitted,

S. H. Libby, *Chairman*
M. C. Maxwell
D. B. Prentice
E. F. Church, Jr.
W. L. Abbott.

EDUCATION AND TRAINING FOR THE INDUSTRIES

The Committee met frequently during the Annual Meeting in December, 1929, to discuss its program for 1930. Another meeting was held in Washington at the Fiftieth Anniversary. Careful consideration was given to a possible survey of one or more industrial districts in which Sections of The American Society of Mechanical Engineers were active. After considerable discussion it was decided that we were not prepared to undertake a larger program at that time.

The Committee prepared a program for the Detroit meeting of the Society which consisted of:

(1) "Training Aeronautical and Automotive Service Mechanics," by A. D. Althouse, Head of Auto and Aero Department, Cass Technical High School.

(2) "Training and Recruitment of Auto Mechanics Through Factory Sources," by William F. Rasche, Principal, Milwaukee Vocational School.

Mr. W. S. Conant, member of the Committee, presided at this meeting.

The Committee also sponsored a meeting in Milwaukee which was organized by Mr. Falk, of the Committee. The subject was "Apprentice Training" and the program was as follows:

(1) "Why Trade Apprenticeship Concerns the Engineer," by Charles Schoen, Works Manager, Kearney and Trecker Corporation.

(2) "Some Aspects of the Local Movement for Apprentice Training," by Harold S. Falk, Vice-President and Works Manager, The Falk Corporation.

(3) Discussion.

(4) Display of work done by apprentices in Milwaukee plants, particularly drawings made by drafting apprentices which would be of greatest interest to the engineer.

A meeting was also held at Richmond, Virginia, on "Apprentice Training" for which Mr. Bailey, Advisory Member of the Committee, was responsible.

Information has been supplied to inquirers interested in setting up training courses.

A program for one session at the Annual Meeting in December has been prepared as follows:

(1) "Apprentice Training in Virginia," by C. F. Bailey, Newport News Shipbuilding and Dry Dock Company.

(2) "The Apprentice Training Movement in Wisconsin Industry," by Harold S. Falk, Vice-President and Works Manager, The Falk Corporation.

(3) Discussion.

(4) "Opportunities for Aviation Training in the Aeronautical Industry," by J. S. Marriott, Chief Inspection Service, Aeronautics Branch, U. S. Department of Commerce.

Mr. Charles H. Colvin, President, The Pioneer Instrument Company, will preside at this meeting.

The main effort of the Committee has been to promote and sustain interest in organized training to improve industrial efficiency. The need for such education has increased since we must largely depend on our national skill rather than on imported artisans.

Respectfully submitted,

R. L. Sackett, *Chairman*
W. S. Conant
J. T. Faig
H. S. Falk
D. C. Jackson
C. F. Bailey } *Advisory*
S. S. Edmands } *Members*

LIBRARY

The Library Committee represents the A.S.M.E. on the Joint Board of the Engineering Societies Library. The report of the Director for 1929 as approved for publication by the Library Board discloses increasing activity and service to the members of the Society.

A notable gift by James H. McGraw makes possible the indexing of past periodical publications, a gap not taken care of by the current indexing done by our Society, and this work will be valuable in research work and will benefit every member who consults the Library. Gifts of money by Mr. William S. Barstow and the late Dr. Ira N. Hollis should be noted, the latter enabling the listing of material in the Library on the history of engineering.

About 38,800 members of the Founder Societies were served during the year, an increase of 5 per cent over 1928. The rental collection continues to serve a specific need of our members.

As indicating the wide interest in the Library, material of value was received from more than 1000 donors during the year. A total of 1329 current periodicals, 50 more than available during the previous year, are on our shelves. Nearly 8000 items of value were added to the main collection during the year and the duplicate collection available for lending has been materially increased. The main collection now numbers more than 135,000 items, and the catalog contains nearly 400,000 cards under 122,238 classifications.

The Library continues to be operated within the budget approved by the Library Board.

Respectfully submitted,

Henry A. Lardner, *Chairman*
Alten S. Miller
George F. Bateman
Ely C. Hutchinson
Calvin W. Rice, *Secretary.*

RESEARCH

Twenty-seven committees were actively at work at the close of the year on a corresponding number of cooperative research projects in most of the important specialized fields of mechanical engineering. Two projects were terminated during the year, Fuels and Spark Arresters, while two new ones were added, Automatic Pumping Stations and Sound Measurement, by action of the Council on the recommendation of the A.S.M.E. Research Committee which administers the Society's research activities. The personnel of the special research committees, which includes both engineering executives and technologists, now totals 409 men, 43 per cent of whom are non-members of the Society.

Financing

Each year's summing-up reveals an increase in industrial support for the experimental programs of the committees. During the past year expenditures from cash contributions made by industry have totaled approximately $50,000, or more than three times the Society's research budget for the same period. In other words, the Society is giving and receiving a technical service, through the published committee reports, worth at least four times its investment. This does not take into account, of course, the expenditure of time and the cost of travel of committee members in this voluntary committee work, an item which probably exceeds to a considerable extent the industrial contributions. It should be recorded also that Engineering Foundation has responded generously to requests for aid to these committees during the first years of their work.

Accomplishments

One of the most tangible results of research committee work is published reports, treatises, and related papers. These have filled sixty-three (63) pages of *Mechanical Engineering*, 237 pages of Transactions, and an unknown number of pages in other technical publications. This material will be available in book form at the time of the 1930 Annual Meeting. Notices of current committee progress and future plans of general news interest have appeared from time to time in the *A.S.M.E. News*.

Two additions have been made this year to the A.S.M.E. Research Publication Series: (1) The third edition of Fluid Meters, Their Theory and Application, Part 1, by the A.S.M.E. Special Research Committee on Fluid Meters, and (2) a bibliography of 800 annotated and indexed references on the Cutting of Metals, by O. W. Boston. The first instalment of an extensive bibliography on Riveted Joints by R. A. deJonge has also been issued in printer's proof form to those concerns which contributed toward the expense involved. It will be generally available in published form when completed. Material has been collected by S. Timoshenko and W. M. Coates for a bibliography and monograph on the Stress Analysis of Pressure Vessels, which may be expected in published form during the coming year.

Committee Progress

A brief review of progress by the various Special and Joint Research Committees follows:

Lubrication. A. E. Flowers, Chairman. Dr. Flowers succeeded M. D. Hersey as Chairman in December, 1929. At that time also Prof. Earle Buckingham was elected Secretary.

The Committee has been successful in raising funds sufficient for the first year of its enlarged experimental program at the Bureau of Standards and work was begun in January, 1930. This work is being directed by Mr. Hersey and includes studies of (1) viscosity at high pressure, (2) factors affecting journal-bearing design, and (3) the phenomena of oiliness. A progress report will be made at the Society's 1930 Annual Meeting. Albert Kingsbury will also present at that time an experimental method for determining pressure distribution in oil films in various types of bearings, with results. This paper is based on a study he has carried on for some time in cooperation with the Committee.

The translations of a number of important foreign papers on lubrication have been completed and it is planned to publish them in a volume together with the most valuable papers that have been presented before the Society on the subject in the past.

Fluid Meters. R. J. S. Pigott, Chairman. During the Society's Annual Meeting, December, 1929, this Committee held a Symposium on Fluid Flow, at which were presented progress reports of the subcommittees and papers by several of their members.

At the invitation of the University of Oklahoma, this Committee held a meeting in Norman, Oklahoma, at the time of the seventh annual Southwestern Gas Measurement Course held by the College of Engineering in April, 1930. The members who were able to attend made a few helpful suggestions on the problems of gas metering and bespoke the cooperation of those present in assisting the Committee to make the fluid-meter reports of maximum benefit to the natural-gas industry.

The Committee was represented during a preliminary discussion of the possibilities of standardization in fluid-flow measurement at the meeting of the International Standards Association in Paris this summer.

The third revision of Part 1 of Fluid Meters, Their Theory and Application, has been completed and published by the Society. Part 2, dealing with the Description of Meters, has been submitted to the A.S.M.E. Research Committee in manuscript form for publication. The manuscript of Part 3, Influence of Installation, will be submitted soon to the members of the Special Research Committee on Fluid Meters for review prior to a meeting in December.

Thermal Properties of Steam. Alex Dow, Chairman. Industry has contributed some $24,000 during the past year to the continuation of the Committee's research program at the Bureau of Standards and Massachusetts Institute of Technology.

Six technical representatives of the Committee attended the Second International Steam Table Conference in Berlin this summer with the German, British, and Czechoslovakian experimenters. Excellent progress was made in the revision of the points and the tolerances of the skeleton table formulated at the First International Conference last year in London. At the close of the three-day conference considerably more experimental data had been included within the scope of the Table. The next conference will be held in the United States in 1932.

The Committee held the usual open conference for the public discussion of its technical progress at the December, 1929, Annual Meeting. Three comprehensive papers written by N. S. Osborne, E. F. Fiock, and N. S. Osborne, H. F. Stimson, and E. F. Fiock, which review the past nine years' work for the Committee at the Bureau of Standards, have been published by the Society and the Bureau. The Society has also published a book containing tentative steam tables and the Mollier diagram formulated by Prof. J. H. Keenan, a member of the Committee, which embodies the most up-to-date data available.

Strength of Gear Teeth. Earle Buckingham, Acting Chairman. In December, 1929, the Committee and the engineering profession in general suffered a great loss through the death of Wilfred Lewis, organizer and chairman of the Committee since its inception.

During the year Professor Buckingham has given a large amount of time to the preparation of an exhaustive report on the results of the Committee's experimental program which he has directed at Massachusetts Institute of Technology during the past four and a half years.

Cutting of Metals. W. W. Nichols, Chairman. The activity in this Committee has centered largely in the Subcommittee on Tungsten Carbide Cutting Materials, F. C. Spencer, Chairman. At the Society's Detroit meeting in June he reported the experiences of some fifty users of these cutting tools, the purpose being to reveal their possibilities and limitations. The committee will conduct a symposium at the December, 1930, Annual Meeting to bring out the relative merits of high-speed tool steel, stellite, and tungsten-carbide cutting tools.

In July the Subcommittee on Cutting Fluids inaugurated an experimental program at the University of Michigan under Prof. O. W. Boston for the purpose of establishing relations between the physical and chemical characteristics of cutting fluids and their performance. This work is being financed by contributions from industry and Engineering Foundation.

In September the Bibliography on Cutting of Metals came off the press. This had been prepared by Professor Boston and presented to the Committee and the Society for publication. It contains some 800 annotated and indexed references.

Mechanical Springs. J. K. Wood, Chairman. The work of Dr. D. J. McAdam on fatigue of helical springs at the U. S. Naval Experiment Station, which had been partially financed for a year by the Committee, was terminated when Dr. McAdam left the station in July. He is now preparing a report on this study. The research of Prof. M. F. Sayre on the elasticity of spring materials at Union College has been continued throughout the year. This work will be reported on at the 1930 Annual Meeting of the Society, as will that of Prof. J. B. Reynolds, who has been cooperating with the Committee on studies of conical spring design at Lehigh University. The Westinghouse Electric and Manufacturing Company reported on its spring research work at the technical sessions sponsored by the Committee and held during the Society's 1929 Annual and 1930 Semi-Annual Meetings. During the year the Committee has continued its policy of distributing quarterly a bibliography of current springs literature to its members and financial contributors.

Messrs. J. R. Townsend, Bell Telephone Laboratories, and C. T. Edgerton, Crucible Steel Company, were elected in June to succeed Messrs. Wood and Rockefeller as Chairman and Secretary, respectively. They take office in December, 1930.

Effect of Temperature on Properties of Metals. H. J. French, Chairman. The experimental program has been continued by the various industrial laboratories cooperating with the Committee in an effort to develop data on which to base test codes for high-temperature tensile and creep tests. Fatigue tests of metals at high temperatures are being carried on at the University of Illinois under the direction of Dr. H. F. Moore and financed by the Committee.

An up-to-date supplement to the Bibliography on the Effect of Temperature on the Properties of Metals, published by the A.S.M.E. in 1928, has been turned over to the Society for publication. Papers

by individuals on the high-temperature properties of metals have been obtained and sponsored by the Committee at meetings of both the A.S.M.E. and the A.S.T.M. during the year. In order to bring out the present high-temperature needs for metals in industry and reveal the possibilities and limitations of present-day metals the Committee is arranging a comprehensive symposium to be held at the A.S.T.M. Annual Meeting in June, 1931.

Prompted by the rapidly growing industrial demand for information on this subject the Committee is now undertaking to raise $20,000 for a three-year research program at some suitable laboratory.

Condenser Tubes. A. E. White, Chairman. During the year the Brooklyn Edison Company has made a preliminary study for the Committee of the effect of air and turbulence on condenser-tube deterioration. The results of this investigation indicate that the present investigation should be widened to include representative operating conditions throughout the power industry. The N.E.L.A. Prime Movers Committee has endorsed the proposal and funds are now being raised to carry it out. The Committee's third progress report was published by the Society during the year.

Boiler Feedwater Studies. S. T. Powell, Chairman. Joint Committee of the A.B.M.A., A.R.E.A., A.W.W.A., N.E.L.A., A.S.T.M., and A.S.M.E. The Committee continued its policy of giving publicity at the Annual and Semi-Annual Meetings of the Society to the great need for a study of boiler-feedwater problems and to progress being made in their solution. Abstracts of the technical literature of the world pertaining to the subject have been regularly supplied the members of the Committee from Chemical Abstracts and the Engineering Index Service.

Boiler Furnace Refractories. W. A. Carter, Chairman. Upon the resignation this year of Dr. C. F. Hirshfeld, who organized and has been chairman of the Committee since its inception, he was succeeded by W. A. Carter as chairman.

At the University of Illinois a satisfactory laboratory method has been developed for testing the resistance of refractories to slag action and thus predicting their service value. Extensive experimental work is now being carried on at the Ceramic Station of the Bureau of Standards and at Battelle Memorial Institute to determine the reactions and equilibria that underlie refractory failures in boiler-furnace operation.

A symposium on slag testing of boiler-furnace refractories has been arranged by the Committee for the Society's 1930 Annual Meeting for the purpose of interesting various industrial concerns in testing their own particular products on the lines laid down by the Committee, thus checking its work and adding to the general data now available. Industry continues to respond generously in financial support to the Committee's program, some $33,000 having been contributed to date.

Elevator Safeties. M. H. Christopherson, Chairman. The Committee has vigorously prosecuted its program of research and code interpretation in connection with the revision of the present American Standard Code for Elevators.

The buffer tests that have been in progress for the past two years on the Committee's experimental elevator at the Bureau of Standards are now completed. Twelve different types of buffers were exhaustively tested under impact by the elevator at various loads and speeds. The data obtained are being used by the elevator industry to improve these devices. A similar examination of undercar safeties is now under way. Some $58,000 has been spent to date by the Committee on this program. Meetings have been held every two months throughout the year to review the results accomplished and to confer with the research associate concerning the experimental program.

Worm Gears. Earle Buckingham, Chairman. The analysis of certain phases of the problem published last year called attention to the values of certain design factors and to the inadequacy of the conventional method for producing worm gears. As a direct result, several concerns are developing new types of production facilities so as to be able to take full advantage of certain neglected design factors. Tests are being carried on also to give quantitative data on the value of these design factors as well as to reveal other information on the action of worm drives.

Welding of Unfired Pressure Vessels. E. H. Ewertz, Chairman. Joint Committee with the American Welding Society. During the year the A.S.M.E. Boiler Code Committee requested this Committee to advise whether a certain type of light-gage welded tank came within the requirements of the Code. Tests were accordingly made at Lehigh University on tanks supplied by the manufacturers. A report is now being prepared.

Spark Arresters. Since the publication and wide distribution last year of the report pointing out that existing types of spark-arresting equipment used on steam-generating apparatus in forest areas seem to be satisfactory if properly applied and maintained, the A.S.M.E. Research Committee has decided that there is nothing further it can do at the present time to foster this cause.

Saws and Knives. A. S. Kurkjian, Chairman. Mr. Kurkjian succeeded Carle M. Bigelow as Chairman in December, 1929. The Committee held a conference of tool and machinery manufacturers and users at the time of the April meeting of the Woodworking Machinery Manufacturers Association in St. Louis, in an effort to initiate a program of cooperative research and standardization. Negotiations are still continuing. The Engineering Foundation has made a grant of $1000 to such a program, contingent on substantial support by industry.

Existing Supplies of Hardwoods. No activity during the year. The Committee is awaiting results of tests being made at the University of Michigan on samples of woods which have been collected in tropical America. These tests are designed to reveal the applicability of tropical woods to the requirements of the American woodworking industries.

Strength of Vessels Under External Pressure. W. D. Halsey, Chairman. Considerable data have been collected both in the United States and abroad from manufacturers and users of this type of vessel concerning their design practice and performance records. This material is being studied with the purpose of evolving reliable design formulas which may be incorporated in the A.S.M.E. Boiler Code.

Absorption of Radiant Heat in Boiler Furnaces. W. J. Wohlenberg, Chairman. Little accomplishment has been reported by this Committee during the past year. It is undertaking, however, to correlate and analyze data submitted from time to time by the power industry on the transfer of heat in boiler furnaces, with the intention of developing practical design formulas.

Fuels. F. R. Wadleigh, Chairman. This Committee was discharged by the Council in May, 1930, because the time did not seem to be right for the functioning of a correlating committee such as this one was intended to be.

Velocity Measurement of Fluid Flow. W. F. Durand, Chairman. Prof. H. E. Hartig and Prof. H. B. Wilcox have continued their experimental work at the University of Minnesota leading to the development of a method of measuring fluid velocities by means of the location of nodal points in wave systems. Engineering Foundation is financing this investigation.

Physical Constants of Refrigerants. Joint sponsorship with the American Society of Refrigerating Engineers to encourage the continuation of research at the National Bureau of Standards on the determination of the physical constants of certain refrigerants. During the past year further efforts have been made to bring about the appropriation of funds by the Federal Government for this project. As a result of these efforts, the Department of Commerce has agreed finally to include such an item in its budget for the fiscal year 1932 and there is a very good expectation that it will be granted. In the interim an attempt is being made to collect $5000 from industry to provide the Bureau of Standards with added facilities until the Governmental funds are available two years hence.

Management Formulas. W. E. Freeland, Chairman. With the aid of this Committee Prof. F. E. Raymond, Massachusetts Institute of Technology, has been making a study of economic production quantities and uneconomical minimum cost production in manufacturing. The results have been reported during the year in two papers read before the Society by Professor Raymond. The Committee is at present engaged in obtaining financial support for a study of the selection and replacement of manufacturing equipment.

Diesel Fuel-Oil Specifications. L. H. Morrison, Chairman. Work has been confined this year to the initiation of field tests throughout the country on the committee's two model fuel-oil specifications for heavy and light Diesel engines suggested last year. The results of these tests indicate that the specifications are not, as yet, complete enough for practical purposes. Accordingly, an experimental investigation of combustion in a Diesel cylinder is being formulated, which it is hoped will furnish the information needed to develop more satisfactory specifications. Two progress reports were published during the year.

Wire Rope. The extensive investigation of the performance of wire rope under various conditions of use which has been conducted during the past two years by the A.S.M.E. Research Committee has resulted in the organization of a special research committee. The first activity of this Committee is in the direction of securing

authentic information and data on the life of wire rope in service. Companies and associations in the various fields of application are being asked to cooperate. Close contact has also been established with the wire-rope investigations being carried on in England and Germany.

Airplane Vibration With Special Reference to Instruments. A. Klemin, Chairman. The Committee has collected considerable information from manufacturers of airplanes, airline operators, and manufacturers of aircraft instruments on their difficulties with the vibration of these instruments. A report will be made at the December, 1930, Annual Meeting of the Society, giving a review of the situation, suggesting practical remedies, and outlining further research that is needed.

Heavy-Duty Anti-Friction Bearings. W. Trinks, Chairman. Contributions from industry of some $4500 early in the year made it possible for the Committee to put a research engineer at work full time on its program of determining the possibilities and limitations of this type of bearing in the operation of rolling mills. Carnegie Institute of Technology has provided office facilities for the research engineer. Considerable data also have been obtained both in the United States and abroad from mill and bearing manufacturers and users relative to the forces acting between rolls and the materials being rolled. A progress report entitled "Forces Acting on Roll-Neck Bearings" has been published by the Society.

Removal of Ash as Molten Slag From Powdered-Coal Furnaces. P. B. Rice, Chairman. Tests have been run throughout the year in the laboratory furnaces set up at the Bureau of Mines in Pittsburgh to study the possibilities of removing ash from powdered-coal furnaces in the form of molten slag. The Bureau is contributing the research facilities and personnel for the investigation, while the Committee is providing materials and special equipment. The work is not yet considered far enough advanced for the publication of a progress report.

Automatic Oil-Pipe-Line Pumping Stations. W. G. Heltzel, Chairman. The organization of this Committee in March, 1930, grew out of the activities of the Society's Mid-Continent Section. Its personnel consists of engineers selected from the pipe-line companies, the power and electrical industries, and the manufacturers of pipe-line equipment in and around Tulsa, Oklahoma. Meeting once a week over a period of more than four months the Committee developed a workable scheme of automatic control and erected an experimental pumping station. This station represents an investment of some $45,000 in donated equipment. A series of tests are now being carried on to determine what changes and refinements are necessary to make the station entirely satisfactory for practical use. The Committee presented a report on its work at the National meeting of the A.S.M.E. Petroleum Division in Tulsa in October of this year.

Methods and Apparatus for Noise Measurement. W. B. White, Chairman. Organized in March, 1930, to conduct an investigation of the instruments and methods for sound measurement now available with a view to the development and establishment of an objective scale for comparison and record. A study of preventable noises in machinery and an investigation of the transmission, absorption, and reflection of sound within buildings from an engineering standpoint are also among its objectives. The Committee is at present attempting the difficult job of formulating the specifications on which to base sound-measurement formulas. Its personnel includes most of the leading technical men in this country familiar with the subject.

Respectfully submitted,

ROBERT L. STREETER, *Chairman*
WILLIAM R. WEBSTER
WALTER H. FULWEILER
ALEX D. BAILEY
ANDREY A. POTTER.

STANDARDIZATION

The annual report of the A.S.M.E. Standardization Committee for the year October 1, 1929, to October 1, 1930, shows considerable progress in the organization of new committees and in the work of the committees previously organized.

ORGANIZATION

The Society in the past year accepted one new sponsorship, that on the Standardization of Pressure and Vacuum Gages, July, 1930, and in the same month proposed jointly with the American Foundrymen's Association the Standardization of Foundry Equipment to the American Standards Association. In addition to these, twenty-seven (27) sectional committees are now sponsored or jointly sponsored by the Society under the procedure of the American Standards Association. Two-hundred and twenty-one (221) subcommittees and subgroups have been formed by these sectional committees in order that the work assigned to them might be carried forward with greater facility. During the current year these subcommittees and subgroups were increased from 186 to 221. The total number of members of these committees is now 1008, of which 384 are members of the A.S.M.E.

At the suggestion of the American Standards Association the A.S.M.E. Standardization Committee at its December, 1929, meeting reviewed the organization and plans of the Sectional Committee on the Standardization of Elevators. It was informed that the proposed standardization could not be undertaken at the present time, owing to the necessity of extensive research. The Committee accordingly voted to approve the discharge of this Sectional Committee.

This year organization meetings of the following committees were held: Sectional Committee on the Standardization of Stock Sizes, Shapes and Lengths for Hot and Cold Finished Iron and Steel Bars, June 3, 1930; Three Technical Committees of the Sectional Committee on Small Tools and Machine Tool Elements—Splines and Splined Shafts, June 9, 1930, Electric Welding Dies and Electrode Holders, June 9, 1930, and Milling Machine Tables, June 19, 1930; and Subcommittee No. 4 on Plumbers' Threads of the Sectional Committee on Standardization of Pipe Threads, October 15, 1929.

During the spring and summer months the personnels of the following committees were developed: Sectional Committee on Pressure and Vacuum Gages; Subcommittee No. 7 on Copper Water-Tube Fittings, Subcommittee No. 8 on Cast Iron Soil Pipe and Fittings, and the Subgroup on Cast Iron Traps of the Sectional Committee on the Standardization of Plumbing Equipment; and Subcommittee No. 6 on Lag Screws and Subcommittee No. 7 on Survey of Present Practice of the Sectional Committee on Standardization and Unification of Screw Threads.

STANDARDS APPROVED

The standards of dimensions and letter symbols completed under the A.S.A. procedure and published in pamphlet form this past year number seven (7). These are the Standards for Slotted Head Proportions (Machine Screws, Cap Screws, and Wood Screws); Ball and Roller Bearings; Cut and Ground Thread Taps; Milling Cutters; Roller Chains, Sprockets, and Cutters; Symbols for Photometry and Illumination; and Navigational and Topographical Symbols. The following six (6) additional standards were completed and placed before the sponsor organizations for approval: 25 Lb. Cast Iron Pipe Flanges and Flanged Fittings; 800 Lb. Hydraulic Cast Iron Pipe Flanges and Flanged Fittings; Symbols for Heat and Thermodynamics; Graphical Symbols for Radio Communication; Woodruff Keys and Keyslots and Cutters; and Track Bolts.

PUBLICITY

During the year thirty-five (35) pages of text pertaining to the work of Standardization were published in *Mechanical Engineering*. Current items of interest were also published in the *A.S.M.E. News*. Publicity has been given also to the standards developed by the sectional committees both in *Mechanical Engineering* and in the technical press by the reproduction of preliminary proposals issued from time to time by the committees. Twenty-five hundred copies of tentative draft standards in printer's proof form were distributed to both the consumer and producer interests during the year.

MECHANICAL STANDARDS ADVISORY COUNCIL

After four years of planning and conferring the Mechanical Standards Advisory Council reported on March 13, 1930, that it was ready to take its place with those groups which have been organized to give advice to their respective industries and to the American Standards Association on questions relative to progress in the standardization of dimensions, codes, and specifications of special interest to the mechanical industries.

Responding to the call of the A.S.M.E. Standardization Committee, a preliminary conference was held in April, 1926, to which fifty organizations known to be interested in standardization were invited. This first conference recommended the organization of an advisory council to the mechanical industries and appointed a Special Committee on Policy, Plan, and Scope.

The report of this Committee was presented at a second conference held in June, 1928, at which a temporary Executive Committee was

elected. The Constitution of the Mechanical Standards Advisory Council was completed in October, 1928, by the temporary Executive Committee and in December, 1928, the Council was called together for permanent organization. A permanent Executive Committee was then appointed and it held its first meeting in New York in December, 1929. At the present time twenty-five organizations have accepted membership in the Council.

A call for a general meeting of the Council has been issued for December 4, 1930, at which a proposed program of activity will be discussed and acted upon.

The A.S.M.E. Standardization Committee has acted as host at these several conferences and has made every effort to bring about the satisfactory organization of this important body.

Sectional and Subcommittee Reports

Shafting. C. M. Chapman, Chairman. During the past year the Sectional Committee has held under advisement the several recommendations previously made for revision of the American Standards for Cold Finished Shafting (1924), Square and Flat Stock Keys (1925), Plane Taper Stock Keys (1927), and Gib Head Taper Stock Keys (1927). Two different recommendations, dealing with the proposed extension of the existing series of flat keys to include keys for shafts larger than six (6) inches in diameter, have been submitted to the members of the Sectional Committee. The first of these was not considered altogether satisfactory, so a second was developed with a view to eliminating the objectionable feature of the first. This proposal will be discussed and acted upon at the next meeting of the Sectional Committee.

Subcommittee on Woodruff Keys. L. C. Morrow, Chairman. After the revisions, prompted by the general distribution of the proposed American Standard for Woodruff Keys, Keyslots, and Cutters, were approved by the Sectional Committee in April, 1930, it was held pending the addition of introductory notes. These were developed during the summer months and approved by the Sectional Committee for inclusion in this proposal. The proposed standard was then submitted to the A.S.M.E. Council for approval. This is expected in October, at which time it will be transmitted to the A.S.A. for its approval and designation as an American Standard.

Plain Limit Gages. The Tentative American Standard for Tolerances, Allowances and Gages for Metal Fits developed by this Sectional Committee was approved by the American Standards Association in December, 1925. Since then approximately 4000 copies have been distributed. In order that this Standard might be reviewed and revised, it was decided to reorganize the Sectional Committee and on September 23, 1930, forty letters of invitation to appoint representatives were sent to interested organizations. The reorganization meeting will probably be held early in December.

Ball and Roller Bearings. F. W. Gurney, Chairman. This Sectional Committee has completed the American Standard on Single Row Sizes and the Recommended Practice on Wide Type of Ball and Roller Bearings. These standards were approved by the American Standards Association in April, 1930.

The standardization of Metric Thrust Bearings and Metric Roller Bearings will be begun upon the receipt of recommendations from the S.A.E. Ball and Roller Bearings Division. The second of these parts of the project is to be interchangeable with the corresponding annual-type ball bearing having the same series numbers. The Committee has continued to review and check the tolerances and allowances of the various types of bearings and the fit of these bearings on the shaft and in the housings.

Gears. B. F. Waterman, Chairman. While no proposals for American Standards have been completed during the year and presented to the A.S.A. for approval and recognition, considerable real progress has been made toward that end by certain of the ten subcommittees.

Subcommittee on Nomenclature. E. W. Miller, Chairman. Through the activities of the Committee of the American Gear Manufacturers Association on this subject a decision has been reached in the controversy covering single and multiple letter symbols. The former are to be designated as "symbols" and the latter as "abbreviations." The manufacturers' committee has developed a list of abbreviations, definitions, formulas, and illustrations of gear terms employed in correspondence concerning Spur, Helical, Herringbone, Bevel, and Worm Gearing. By mutual consent, therefore, the Subcommittee is undertaking to supply a list of corresponding single-letter symbols.

Subcommittee on Spur Gear Tooth Form. H. J. Eberhardt, Chairman. The Committee held a meeting in Cleveland in May, 1929, for the consideration of the criticisms and comments which had been received as a direct result of the distribution of printer's proof copies of 14½-Degree and 20-Degree Full Depth Involute Gear Tooth Forms. This revision is now completed and the proposal will soon go to the Sectional Committee for approval by letter ballot. Messrs. F. W. England and J. P. Breuer have been added to this Subcommittee.

Subcommittee on Materials. T. D. Lynch, Chairman. During the year the Committee has reviewed the large number of replies which were received as a direct result of the distribution of printer's proof copies of the proposed American Standard for Gear Materials and Blanks. Within a month or so this proposal should go to the Sectional Committee for approval by letter ballot.

Subcommittee on Inspection. G. L. Markland, Jr., Chairman. At the two meetings which this Subcommittee held during the year the large volume of comment received by mail was carefully reviewed. This work is still in progress. At the last meeting a considerable increase in the personnel of the Committee was made.

A. A. Ross has been made Chairman of the Subcommittee on Helical Gears and the Committee has drafted a proposal on Herringbone Gears. No definite progress has been made this year by the Subcommittees on Worm Gears, Bevel Gears, and Horsepower Rating.

Pipe Flanges and Fittings. C. P. Bliss, Chairman. This year the Sectional Committee completed and approved two proposed American Standards, namely, those for the 800 Lb. Hydraulic Cast Iron Pipe Flanges and Flanged Fittings and the 25 Lb. Cast Iron Pipe Flanges and Flanged Fittings. The Chairman reports satisfactory progress by the several subcommittees.

Subcommittee No. 1 on Cast Iron Flanges and Flanged Fittings. A. M. Houser, Chairman. This Committee completed during the year the proposed 800 Lb. Hydraulic Standard which in November, 1929, was approved by the Sectional Committee and subsequently submitted to the three Sponsors. The Heating and Piping Contractors National Association and the A.S.M.E. gave their respective approvals in January. The approval of the Manufacturers Standardization Society of the Valve and Fittings Industry, however, was given conditionally pending changes in the section pertaining to Markings and Materials.

The Standard for 25 Lb. Cast Iron Pipe Flanges and Flanged Fittings as proposed by this Subcommittee was approved by the Sectional Committee and the Sponsors. In September it was submitted to the A.S.A. for approval and designation as an American Standard.

The proposed standard for Ammonia Fittings was completed by the manufacturers' subgroup of this Subcommittee in May. It will be discussed at a meeting of the Refrigerating Machinery Association to be held at St. Louis in October.

Subcommittee No. 2 on Screwed Fittings. S. G. Flagg, Jr., Chairman. This Committee has approved for general distribution to industry for review and comment a proposed standard for Pipe Plugs of Cast Iron, Malleable Iron, Cast Steel, and Forged Steel. This canvass of industry will be completed early in October.

Subcommittee No. 3 on Steel Flanges and Flanged Fittings. C. P. Bliss, Chairman. In December, 1929, this Subcommittee sent out a questionnaire concerning the performance of companion flanges and flanged equipment made to the dimensions of the American Tentative Standard for Steel Pipe Flanges and Flanged Fittings. Based on the replies received certain revisions were made in the Committee's original proposal for companion flanges. This revised draft, now in proof form, will be discussed at the October meeting of the Subcommittee. In addition a proposed Standard for Steel Base-Fittings for 250, 400, 600, and 900 Lb. per Sq. In. has been completed by the Subcommittee and is to be distributed immediately to industry for comment.

The Subcommittee's new proposals for 120, 150, and 1500 Lb. Steel Pipe Flanges and Flanged Fittings are to be discussed at the October meeting.

Subcommittee No. 5 on Face to Face Dimensions of Ferrous Flanged Valves. F. H. Morehead, Chairman. The work of this Subcommittee is progressing slowly. The M.S.S.V.F.I. recently requested that the Committee exclude from its scope for the present the standardization of face-to-face dimensions of valves rated at 150 lb. and 400 lb. W.S.P.

Subcommittee No. 6 on Malleable Iron or Steel Brass Seat Unions. C. P. Bliss, Temporary Chairman. The manufacturers' subgroup of this Subcommittee has held three meetings during the past year and considerable progress has been made in collaboration with the A.R.A. Subcommittee on Locomotive Design and Construction, toward formulating a proposed American Standard for 300 Lb. Ground Joint Unions and Combination Union Fittings. This

proposal will soon be released by the Subgroup, at which time it will be set in type for consideration by the Subcommittee and industry in general.

Subcommittee No. 8 on Marking of Pipe Fittings. W. S. Morrison, Chairman. This Subcommittee sent out a questionnaire in December, 1929, in order to obtain an expression from industry as to whether or not markings were necessary, could be put on the fittings, and how they should be applied. To this a very fair response was received representing a great diversity of opinion. One of the sponsors of this project, the M.S.S.V.F.I., is making a similar study.

The following two Subcommittees did not meet during the year: Subcommittee No. 4 on Materials and Stresses, A. M. Houser, Chairman, and Subcommittee No. 7 on Rating of Pipe Fittings, H. C. Heaton, Chairman. No specific progress has been reported.

Bolt, Nut, and Rivet Proportions. A. E. Norton, Chairman. Since its organization this Sectional Committee has presented six standards for approval as an American Standard and publication. The latest standard to receive this designation is that on "Slotted Head Proportions," April, 1930.

Subcommittee No. 1 on Large and Small Rivets. J. E. J. Kiernan, Chairman. Since the distribution in March, 1928, of the proposal for Large Rivets by the Subcommittee it has been working on proposed tolerances. When the replies to its April, 1930, letters on proposed tolerances have been completely reviewed, it is expected that the Subcommittee will release its revised proposal to the Sectional Committee. Two standards developed by this Subcommittee have been approved as American Standards, Small Rivets (1927), and Tinners', Coopers', and Belt Rivets (1928).

Subcommittee No. 2 on Wrench Head Bolts and Nuts. H. A. Spanagel, Chairman. During the year this Subcommittee has been at work revising the American Tentative Standard which was approved by the A.S.A. in February, 1927. A meeting was held in Detroit in June, 1930, to discuss in detail the proposed revisions. The members of the Committee had previously agreed to certain changes in nut sizes on the recommendations of the Bolt, Nut, and Rivet Manufacturers Association.

Subcommittee No. 3 on Slotted Head Proportions. E. Winsor Reed, Chairman. The American Standard for Slotted Head Proportions was approved by the American Standards Association in April, 1930, and was published in pamphlet form by the A.S.M.E.

Subcommittee No. 4 on Track Bolts. C. W. Squier, Chairman. The sponsors approved the proposed standard for Track Bolts within these twelve months and presented it to the American Standards Association in September, 1930, for approval and designation as an American Standard.

Subcommittee No. 9 on Socket Head Cap and Set Screws. H. Koester, Chairman. The Subcommittee held meetings in October, 1929, and in September, 1930, to discuss its preliminary proposal, which will be set in type very shortly for general distribution for criticism and comment.

Identification of Piping Systems. A. S. Hebble, Chairman. This Committee prepared the present American Recommended Practice entitled "Scheme for the Identification of Piping Systems," which was approved by the A.S.A. in November, 1928. There was no need for activity this year.

Small Tools and Machine Tool Elements. C. W. Spicer, Chairman. This Sectional Committee met in December, 1929, to review and plan the work of the various technical committees under its supervision. At this meeting the organization of three new technical committees was approved: (1) Electric Welding Dies and Electrode Holders; (2) Splines and Splined Shafts; and (3) Milling Machine Tables.

Four of this Sectional Committee's Standards have been approved by the A.S.A. so far: T-Slots, Their Bolts, Nuts, Tongues, and Cutters, March, 1927; Tool Holder Shanks and Tool Post Openings, April, 1929; Milling Cutters, April, 1930; and Cut and Ground Thread Taps, April, 1930.

Technical Committee No. 3 on Machine Tapers. E. F. DuBrul, Chairman. A meeting of this Committee was held in December, 1929, at which the results of the questionnaire sent to 650 companies were discussed. At this meeting a Subgroup on Dimensions, Tolerances, and Gages was appointed. The Technical Committee plans to meet on October 20 to receive the report of the Subgroup.

Technical Committee No. 4 on Spindle Noses and Collets for Machine Tools. E. F. DuBrul, Chairman. Technical Committee No. 4 met jointly with Technical Committee No. 11 on Chucks and Chuck Jaws on June 10 to discuss the replies received as a result of the distribution of copies of the joint proposal made by these two Technical Committees and distributed in May, 1930, for general criticism and comment. At this meeting a Subgroup was appointed, with J. E. Lovely as Chairman, to study and correlate the spindle nose proposals submitted with the comments and to develop a new proposal. As a part of the activity of this Subgroup sample chucks of the several proposed standard designs are being made and sent to a machine-tool manufacturer in Cincinnati, where comparative tests will be made for the committee. The Committee will hold its next meeting on October 21.

Technical Committee No. 5 on Milling Cutters. C. W. Machon, Chairman. The final recommendations of four of the subgroups of this Technical Committee, namely, Sections of Profile Cutters, Keyways, Nomenclature, and Formed Cutters, were completed during the year, edited, and approved by the Sectional Committee, the sponsors, and the A.S.A. Combined in one pamphlet they were published as an American Standard for Milling Cutters, April, 1930.

Technical Committee No. 6 on Designations and Working Ranges of Machine Tools. E. F. DuBrull, Chairman. This Technical Committee since its organization meeting in December, 1928, has been gathering data for its first report. It now plans to meet on October 20 to review these data.

Technical Committee No. 7 on Twist Drill Sizes. C. J. Oxford, Chairman; and Technical Committee No. 8 on Drill Bushings, C. E. Rundorff, Chairman. These two committees have held three joint meetings during the past year in Cleveland, Detroit, and New York. At one of these meetings subgroups were appointed to study Lengths and Diameters of Drills, and Liner Outer Diameters and Tolerances of Bushings. At the June meeting in Detroit the comments received as the result of the distribution of the 450 copies of Proposal "C" on Twist Drill Sizes and Lengths (Straight Shanks) were discussed. This proposal included a supplementary table comparing the proposed sizes with the present ones. These Committees have called their next joint meeting for the first week in December in New York.

Technical Committee No. 9 on Punch and Die Holders. S. Diamant, Chairman. At the December, 1929, meeting the committee found it desirable to increase its personnel by adding four new members. It decided to combine Subgroups 1 and 2, Styles and Materials, as it had been found that their work overlapped. The work of collecting and correlating data on Styles and Sizes with a view to eliminating certain sizes, authorized at the last meeting, has progressed satisfactorily so that a meeting of the Committee is planned for the first week in December.

Technical Committee No. 10 on Circular Forming Tools and Holders. This project was approved by the Executive Committee in 1928. However, in attempting to organize the Committee very little interest in the subject was found. The work will probably be dropped for the present.

Technical Committee No. 11 on Chucks and Chuck Jaws. J. E. Lovely, Chairman. The first proposal of this Committee, combined with that on Spindle Noses, was broadly distributed in May, 1930. At a joint meeting of the two Committees held in Detroit in June it was decided to separate the section on Chucks and Chuck Jaws from that on Spindle Noses. This was done and the committee has scheduled a meeting for October for the purpose of reviewing the progress made during the summer months preliminary to a restatement of its proposal in tabular form.

Technical Committee No. 12 on Cut and Ground Thread Taps. C. M. Pond, Chairman. The American Standard for Cut and Ground Thread Taps was approved by the American Standards Association in April, 1930, and is now in pamphlet form.

Technical Committee No. 13 on Splines and Splined Shafts. C. W. Spicer, Chairman. The organization of this Committee was authorized at the meeting of the Sectional Committee held in December, 1929. At the first meeting, which took place in Detroit in June, 1930, the members of the committee were requested to collect all the data available on this subject in the files of their companies and to forward copies to the Chairman so that such data might be distributed with the minutes of the meeting for study and correlation by the members of the Committee.

Technical Committee No. 14 on Electric Welding Dies and Electrode Holders. J. A. Weiger, Chairman. At its organization meeting held in Detroit in June the Committee decided to direct its attention first to the standardization of arms, holders, and tips of electric-resistance spot-welding machines. A second meeting of the Committee was held in Chicago in September, 1930, at which plans were made for the distribution of a questionnaire to the manufacturers and users of this equipment covering the above items.

Technical Committee No. 15 on Milling Machine Tables. G. A. Bouvier, Chairman. The organization of this Committee was

authorized at the December, 1929, meeting of the Sectional Committee and its first meeting was held in June, 1930, at Detroit. At this time a subgroup was appointed to draft a proposal covering the tee-slot spacing for the several present sizes of tables. Data which deal with the cross-sections of the various types of milling-machine tables are now being collected by the Committee for study at its next meeting.

Scientific and Engineering Symbols and Abbreviations. J. F. Meyer, Chairman. The Committee's ambition to complete the standards on its present list during 1930 has been practically realized. Since its organization in 1926 seven (7) standards developed by the Committee have been approved by the American Standards Association and published in pamphlet form. In addition, two (2) proposed standards are now before the A.S.A. A more detailed statement of the work of the Committee follows.

Subcommittee on Symbols for Mechanics, Structural Engineering, and Testing Materials. J. T. Faig, Chairman. The criticisms and comments received from the general distribution of the preliminary report of the Committee are now in the hands of the Chairman. A revision of the proposed standard will be accordingly ready in a short time for transmission to the Sectional Committee for study and approval.

Subcommittee on Symbols for Heat and Thermodynamics. S. A. Moss, Chairman. This proposal has been approved by the Sectional Committee and the approval of the five sponsor bodies was completed in September. The standard is accordingly before the A.S.A. for final approval and recognition as an American Standard.

Subcommittee on Symbols for Photometry and Illumination. E. C. Crittenden, Chairman. The proposal of this Committee was finally approved and published in August, 1930. The standard consists of a revision of the symbols contained in "Illuminating Engineering Nomenclature and Photometric Standards" which was formulated under the sponsorship of the Illuminating Engineering Society and adopted as an American Standard in 1925.

Subcommittee on Electrotechnical Symbols Including Radio. J. F. Meyer, Chairman. The proposed standard on Graphical Symbols for Radio Communication is now before the A.S.A. for approval. Two other standards prepared by this Subcommittee have been finally approved, Letter Symbols for Electrical Quantities, approved in February, 1929, and Graphical Symbols for Telephone and Telegraph Use, approved in July, 1929. The Subcommittee is now engaged in the development of Symbols for Electric Power including Interior Wiring, Traction and Railway Signaling.

Subcommittee on Navigational and Topographical Symbols. G. L. Hosmer, Chairman. The first proposed standard to come from this Subcommittee was approved by the A.S.A. in July, 1930. It will be published shortly.

Subcommittee on Abbreviations for Engineering and Scientific Terms. G. A. Stetson, Chairman. The members of the Subcommittee have spent the year in refining the proposal made last year. A committee of the A.I.E.E. has cooperated with it relative to the abbreviations of certain electrical terms.

Plain and Lock Washers. C. W. Squier, Chairman. The Chairman of Subcommittee No. 1 on Plain Washers, F. Doepke, reports that this Subcommittee has not its proposal in shape for submittal to industry for comment. Subcommittee No. 2 on Lock Washers, of which C. H. Loutrel is Chairman, met in December, 1929, at which time it was decided to include methods of testing in this standard. The Committee plans to develop these methods of test and, together with a table of dimensions, to release the proposed standard to industry shortly for general criticism and comment.

Machine Pins. M. E. Steczynski, Chairman. This Sectional Committee in September, 1930, distributed a proposal on Taper and Cylindrical Machine Pins to industry for criticism and comment. A considerable number of helpful criticisms have been received, so it is very likely that a meeting of the Committee will be held in December.

Code for Pressure Piping. E. B. Ricketts, Chairman. The Sectional Committee has held two meetings during the past year, one at New York in December, 1929, the other at Detroit in June, 1930. At both of these meetings the progress reports of the several Subcommittees were submitted and discussed at length.

Subcommittee on Power Piping. J. H. Lawrence, Chairman. The Subcommittee has been actively engaged in the revision of the previous draft of the Power Piping section of the Code and the redrafted portions were discussed at two meetings, one held at New York in December, 1929, and the other at Detroit in June, 1930. While considerable progress has been made, this section is not, as yet, in final form.

Subcommittee on Gas and Air Piping. A. Iddles, Chairman. The work of this Subcommittee has progressed to a point where its section of the Code is in final form except for possible changes which may be made necessary as a result of requests from the natural-gas industry. It is expected that a final draft will be completed before the meeting of the Sectional Committee in December, 1930.

Subcommittee on Refrigerating Piping. A. H. Baer, Chairman. The Subcommittee has experienced considerable difficulty in drafting the section on refrigerating piping, but has recently reported that it expects to release its first proposal for general distribution in the near future.

Subcommittee on Oil Piping. A. D. Sanderson, Chairman. Some slight modifications have been made during the past year in this section of the Code and these, including a section for higher temperature and pressures and some modifications in the cast-iron-pipe requirements, were discussed at a meeting held at Detroit in June, 1930.

Subcommittee on Piping Materials. F. H. Morehead, Chairman. The first meeting of this Subcommittee since its organization was held at Detroit in June, 1930. It was decided there that the Committee should abandon the plan of abstracting specifications and should report in their entirety all specifications for materials applicable to pressure piping. Progress in gathering these data has been reported since the meeting.

Subcommittee on Fabrication Details. C. G. Spencer, Chairman. A meeting of this Subcommittee was held in June at Detroit and the progress made by the various Subgroups was discussed, considerable time being given to welding and the qualifications of welders. In June, after the Detroit meeting, a draft proposal on Fabrication of Hangers, Supports, Anchors, Sway Bracing, and Vibration Dampeners was sent to all members of the Subcommittee and Sectional Committee for consideration and criticism. The Subgroup on Joints Other Than Welded distributed a questionnaire to industry during the summer and replies will be discussed at the next meeting.

Drawings and Drafting Room Practice. F. DeR. Furman, Chairman. During the Annual Meeting of the Society in December, 1929, this Sectional Committee held a meeting at which time a Subcommittee on Editing was appointed, consisting of the Chairman of each of the six Subcommittees. Professor T. E. French was appointed Chairman of this new Subcommittee.

Three of the Subcommittees, those on Method of Indicating Dimensions, Lettering, and Line Work, distributed proposals for criticism and comment the latter part of 1929. These proposals attracted considerable attention on the part of industry and the extensive comments received are now being studied by the members of these Subcommittees, preparatory to redrafting and review by the members of the Sectional Committee.

Subcommittee on Layout. D. Baker, Chairman. F. G. Wolff, who has been acting as Chairman of this Subcommittee, found it necessary to resign, and D. Baker was appointed to carry on its work. A first report in the form of a definite proposal was presented to the Sectional Committee in January, 1928.

Subcommittee on Graphical Symbols for Drawings. T. E. French, Chairman. This Committee has had during the year a similar experience to that of the Subcommittee on Layout. G. H. Drake, who has been acting as Chairman since its organization, was unable to continue, so Prof. T. E. French was appointed to carry on the work. A set of proposed standard symbols for plumbing fixtures was distributed for criticism and comment to a selected list of architects in the United States and members of the American Institute of Architects. The replies received were then duplicated and distributed to the members of the Sectional Committee.

Graphic Presentation. E. F. DuBrul, Chairman. The Sectional Committee on Graphical Presentation was organized in November, 1926, since which time its various Subcommittees have been developing the individual sections of the proposed standard.

Subcommittee on Terminology. R. J. McFall, Chairman. For the past two years this Committee has been working on the enlargement of the section on terminology originally distributed in November, 1928. At the time of this distribution the replies indicated the necessity of extending its scope.

Subcommittee on Survey of Current Practice. A. H. Richardson, Chairman. Current practice in graphical presentation has been studied intensively by this Subcommittee with the result that it has collected a very large amount of information. It has invited the Subcommittees on Time Series Charts and Non-Time Series Charts to meet with it in a joint meeting early in October for the purpose of studying this material which Chairman Richardson has carefully analyzed and coordinated.

Subcommittee on Engineering and Scientific Graphs. W. A. Shewhart, Chairman. Through the activities of the Subcommittee a Round Table Conference on the Analysis and Presentation of Data was held during the Annual Meeting of the A.S.M.E. in December, 1929. The attendance at this Conference numbered more than 80 and one of the resolutions passed recommended the appointment of a Joint Committee for the Development of Statistical Applications in Engineering and Manufacturing, the personnel of which is to consist of representatives of the American Statistical Association, the American Mathematical Society, the American Society for Testing Materials, and the A.S.M.E. This Committee has since been appointed and is now functioning. At the present time the Subcommittee is making arrangements for an open meeting to be held during the 1930 Annual Meeting of the Society.

Transmission Chains and Sprockets. F. V. Hetzel, Chairman. The first of this Sectional Committee's standards for Roller Chains, Sprockets, and Cutters was approved by the American Standards Association in July, 1930. This standard is now available in pamphlet form as an S.A.E. publication. The committee is now at work on a proposal for Silent Chains.

Wire and Sheet Metal Gaging Systems. W. W. Hutchins, Chairman. This Sectional Committee's three Subcommittees on Flat Stocks, Wires and Rods, and Tubing, Piping, Conduit and Casing have not reported any progress during the past year.

Electric Motor Frame Dimensions. W. F. Dixon, Chairman. In December, 1929, this Sectional Committee approved the proposed standard for Mounting Dimensions of Low-Voltage 60-Cycle Squirrel-Cage Induction Motors. The joint sponsors, the N.E.M.A. and A.S.M.E., gave their approval in November, 1929, and January, 1930, respectively. In April, 1930, it was submitted to the A.S.A. for approval and designation as an American Standard. Since that date the N.E.M.A. has requested the A.S.A. to withhold approval of this standard.

Pipe Threads. E. M. Herr, Chairman. Within the twelve months of the past year two of the Subcommittees of the Sectional Committee on Pipe Threads held meetings. The progress made at these meetings is recorded in the following paragraphs.

Subcommittee on Taper Pipe Threads. S. B. Terry, Chairman. In April, 1930, this Subcommittee held its first meeting. The relation between the A.P.I. Standard Line Pipe Thread and the American Standard was thoroughly discussed and a Subgroup was appointed to confer with the A.P.I. Committee in Chicago next November. Consideration was then given to the content and form of the American Standard pamphlet (B2–1919) and it was decided to make no change in the form of thread, taper, pitch, and terminology.

Subcommittee on Plumbers' Threads. L. A. Cornelius, Chairman. At its organization meeting in October, 1929, the Committee discussed at length the specifications for (1) Plumbers' Fine Threads and (2) Corporation and Cutoff Cocks. Subgroups were then appointed to develop the details of proposed standards for these two applications.

The Subcommittees on Straight Pipe Threads, Screw Threads for Rigid Conduit, and Threads for Thin Tubes have held meetings previously, and are awaiting the recommendations of the Subcommittee on Taper Pipe Threads before completing their proposals.

Wrought Iron and Wrought Steel Pipe and Tubing. H. H. Morgan, Chairman. In June, 1930, the Sectional Committee met in Detroit to consider the formula for calculating nominal pipe-wall thickness as developed by the Subgroup on Basic Formulas and proposed jointly by Subcommittees Nos. 2 and 3. The formula, which had been evolved is a modification of the Barlow Formula and favored by the A.S.M.E. Boiler Code Committee, seemed to meet the requirements of pipe-wall thickness calculations, so was approved at this meeting subject to vote by letter ballot. It was recommended that, as the next step, tentative wall-thickness schedules based on this formula should be prepared and referred to Subcommittees Nos. 2 and 3.

Subcommittee on Plan, Scope, and Editing. H. H. Morgan, Chairman. This Subcommittee met in Detroit in March and in June, 1930, for an advance discussion of the problems before the Sectional Committee and to plan for the development of this project.

Subcommittee on Pipe and Tubing for Low Temperature Service. J. J. Shuman, Chairman, and Subcommittee on Pipe and Tubing for High Temperature Service, H. H. Murray, Chairman. A joint meeting of these two Subcommittees was held on June 10 prior to the Sectional Committee meeting. The two Subcommittees approved the formula for pipe-wall thickness and recommended its submission to the Sectional Committee for approval. Upon the approval of this formula by the Sectional Committee the two Subcommittees began the preparation of schedules of pipe and tubing sizes and weights covering the ranges needed by industry.

Speeds of Machinery. A. E. Hall, Chairman. The Sectional Committee on Speeds of Machinery was organized in October, 1928. The Subcommittee on Plan and Scope met last December and appointed a subcommittee on Questionnaire and Canvass of Industry. Mr. English, Temporary Chairman of this newly appointed committee, plans to call the first meeting at the time of the A.S.M.E. Annual Meeting in December.

Fire-Hose Couplings. Since the approval in May, 1925, of the American Standard for Fire-Hose Couplings Threads, there has been a steady increase in its acceptance by cities and towns of the United States. The National Board of Fire Underwriters, the Chamber of Commerce of the United States, and the A.S.M.E. Local Sections have assisted in the promulgation of this standard and in increasing the use of gages by municipal authorities in accepting equipment. The conversion of existing equipment to this standard also is progressing satisfactorily. The N.B. of F.U. makes an annual canvass of the cities on this subject.

Screw Threads for Hose Couplings. H. W. Bearce, Chairman. The Sectional Committee met in July, 1930, to review and discuss the draft of the proposed standard for Small Hose Coupling Screw Threads for All Connections having Nominal Inside Diameters of 1/2, 3/4, 1, 1 1/4, 1 1/2 and 2 Inches, which had been drafted by a Subcommittee. Based on the discussion at this meeting a revised draft of the proposal was prepared. This is being set in type for distribution for criticism and comment prior to further action by the Sectional Committee.

Plumbing Equipment. W. C. Groeniger, Chairman. At the time of the organization of the Sectional Committee on Standardization of Plumbing Equipment in August, 1928, six Subcommittees were appointed. This spring it was found desirable to appoint two more Subcommittees to develop the sections on Copper Water Tube Fittings (No. 7) and Cast Iron Soil Pipe and Fittings (No. 8). The work of organizing these two Committees and the Subgroup on Cast Iron Traps has been carried on during the spring and summer with the result that meetings of all three will be held very shortly.

Subcommittees: No. 1 on Plumbing Code, No. 2 on Staple Vitreous China Plumbing Fixtures, No. 3 on Staple Porcelain (All Clay) Plumbing Fixtures, and No. 4 on Enameled Sanitary Ware have the same personnel as the Standing Committees on the same subjects organized by the U. S. Department of Commerce.

Subcommittee No. 5 on Traps. A. R. McGonegal, Chairman. The organization meeting of the Subcommittee on Traps was held in January, 1930. At that meeting the necessity for the appointment of Subgroups to develop the proposals for traps in the following seven classes was made evident: Brass lavatories and sinks; brass; cast iron; lead; vitreous china; miscellaneous traps; interceptors and catch basins. The Subgroup on Brass Lavatories and Sink Traps met in New York on March 18. The other Subgroups, while not completing their proposals, have reported progress.

Subcommittee No. 6 on Brass Plumbing Products. J. L. Murphy, Chairman. The Subgroup on Compression Cocks, Washer Screws, Faucets, and Tail Piece Parts has sent copies of its recommendations, based on the replies to its questionnaire to manufacturers, to the members of the Subcommittee for comment.

Subcommittee No. 7 on Copper Water Tube Fittings. The proposal on Brass Fittings for Flared Copper Tubes is the first of the Sectional Committee's proposals to be set in type. Copies will shortly be distributed for general criticism and comment.

Standardization and Unification of Screw Threads. R. E. Flanders, Chairman. Through the activities of its Subcommittees this Sectional Committee has made very substantial progress toward the completion of its task during the past year. A meeting is scheduled for October 16 to receive and review the reports of these Subcommittees.

Subcommittee on Scope, Arrangement, and Editing. R. E. Flanders, Chairman. Two meetings of this Committee were held, one in October, 1929, and the other in April, 1930. The first meeting was devoted to a careful review of the 1928 report of the National Screw Thread Commission and the assignment of its several sections to the Subcommittees for further study and report. At this meeting the Committee considered also certain special screw-thread applications not definitely covered by the N.S.T.C. report.

At the second meeting, on the recommendation of the wood-screw manufacturers, it was decided that there was no consistent demand for the standardization of the thread form of wood screws. A similar action was taken concerning screw threads for valve stems.

Plans for the survey of current screw-thread practice proposed and approved at the May, 1929, meeting of the Sectional Committee were discussed and developed at these two meetings.

Subcommittee on Terminology and Thread Specifications, Except Gages. C. W. Bettcher, Chairman. At its April 7, 1930, meeting this Subcommittee made a detailed study of the pamphlet describing the present American Standard (B 1a–1924) and the corresponding sections and paragraphs of the N.S.T.C. reports of 1924 and 1928. Its recommendations will be discussed by the Sectional Committee when it meets.

Subcommittee on Special Threads and Twelve Pitch Series, Except Gages. The organization meeting of this Subcommittee was held on April 10, 1930. Three of its actions are of special interest: (1) Approval of the twelve (12) pitch series as published in the 1928 report of the N.S.T.C., (2) naming of Subgroups to develop dimensions and tolerances for a new eight (8) pitch series, and (3) the appointment of a Subgroup to study the possibilities of establishing a standard screw thread for track bolts.

Subcommittee on Screw Thread Gages and Inspection. G. S. Case, Temporary Chairman. At its meeting in April, 1930, the Subcommittee on Screw Thread Gages and Inspection discussed the scope of its work with the result that it was decided to limit the present activities to (*a*) classification of gages, (*b*) gage tolerances, and (*c*) gages appearing in the 1928 report of the N.S.T.C. A Subgroup of three was appointed to draft recommendations.

Subcommittee on Survey of Present Practice. R. E. Flanders, Chairman. Through discussion at the various meetings of the Sectional Committee and the several Subcommittees certain features of the Survey of Present Practice have been determined. They are as follows:

(1) The samples will be gathered by an official representative of the Committee;
(2) These samples will be mailed to the Gage Division of the Bureau of Standards where they will be gaged;
(3) Approximately 100 concerns, both manufacturers and users, will be visited and certain information concerning the manufacture or use of the product will be recorded at that time; and,
(4) The list of firms has been prepared so as to cover adequately the major screw-thread manufacturing and using industries located in the eastern and the east-central sections of the United States.

Subcommittee on Acme and other Similar Threads, except Gages, and Subcommittee on Lag Screws did not hold meetings during the year but have made some progress by correspondence.

Rolled Threads for Screw Shells of Electric Sockets and Lamp Bases. R. E. Myers, Chairman. The Sectional Committee on the Standardization of Rolled Threads for Screw Shells of Electric Sockets and Lamp Bases was organized in March, 1929. After several meetings Subcommittee No. 1 released its proposed standard for general criticism. The replies are to be discussed at a meeting on October 2, after which the proposal will be submitted to letter ballot of the Sectional Committee.

Stock Sizes, Shapes, and Lengths for Hot and Cold Finished Iron and Steel Bars. F. H. Frankland, Temporary Chairman. The organization meeting of the Sectional Committee was held on June 4, 1930. The appointment of three Subcommittees was authorized, No. 1 on Hot Rolled Steels, No. 2 on Cold Finished Steels, and No. 3 on Hot Rolled Iron. The personnels of these three Subcommittees are now being completed.

Pressure and Vacuum Gages. Sponsorship for this project was assigned to the Society in June, 1930, by the American Standards Association. Accordingly, early in July letters of invitation were mailed to fifty-five (55) associations and societies requesting them to appoint official representatives on the Committee. As soon as a sufficient number of appointments have been made the Committee will be called together for organization. It is expected that this meeting will be held before January 1.

Respectfully submitted,

EDWARD J. KEARNEY, *Chairman*
H. BIRCHARD TAYLOR
LEWIS K. SILLCOX
WILLIAM S. MONROE
EARLE BUCKINGHAM.

SAFETY

The Standing Committee on Safety reports the following progress in the safety activities of the Society.

PUBLICITY

Throughout the year the Committee has continued its efforts to keep the importance of industrial safety before the technical sessions of the Society. In April, 1930, Chairman Mowery addressed letters to the members of the Executive Committees of the A.S.M.E. Professional Divisions in charge of papers and meetings suggesting that provision be made for five-minute talks on safety at their sessions on subjects closely relating to that of the session. At the Detroit Meeting in June a brief talk on safety was given at the Management Session.

During the summer months a considerable amount of work has been done in preparation for the safety features of the 1930 Annual Meeting. At this date it can be reported that a Symposium on Safety will be held on Monday, December 1, and a joint session on Safety and the Wood Industries has been arranged for Wednesday of Annual Meeting Week.

During the year a number of articles totaling two pages of text has been published in *Mechanical Engineering* and items of general and timely interest have been run in issues of the *A.S.M.E. News*.

NEW YORK BUILDING CODE COMMITTEES

On March 13, 1930, the Committee called an informal conference of its members and the seventeen A.S.M.E. members serving on Committees which are formulating the new Building Code of the City of New York. The conference was held for the purpose of discussing ways and means whereby the Society as an organization might help in this important work. The meeting recommended that a joint committee of the American Institute of Architects and the A.S.M.E. be appointed to review the proposed revised Building Code when it is nearly completed and to make recommendations, if necessary, to the Advisory Committee of the Building Code Committee.

SAFETY CODES

Five of the fifty safety-code committees now functioning under the procedure of the American Standards Association are sponsored solely or jointly by the A.S.M.E. These are:

Sectional Committee on a Safety Code for Mechanical Power Transmission Apparatus
Sectional Committee on a Safety Code for Elevators
Sectional Committee on a Safety Code for Machinery for Compressing Air
Sectional Committee on a Safety Code for Conveyors and Conveying Machinery
Sectional Committee on a Safety Code for Cranes, Derricks, and Hoists.

In addition to these Committees the Society has representation on 23 other Sectional Committees drafting safety codes.

PERSONNEL

The Sectional Committees on Safety Codes sponsored by the A.S.M.E. now have a membership of 218. Of this number 91 are members of the Society. These five Committees have subdivided their work among 22 subcommittees and subgroups, making a total of 27 committees at work on the Society's safety program.

ACTIVITIES OF SECTIONAL COMMITTEES

The Subcommittee on Research, Interpretations, and Recommendations formed in 1926 to develop reliable data on certain auxiliary apparatus for the revision of the Safety Code for Elevators, approved and published in 1925, continued its monthly meetings during the year. Its work was advanced to a stage where a revision of the Code was possible and in July, 1930, a revised draft was submitted to the members of the Sectional Committee on a Safety Code for Elevators for approval by letter ballot. This ballot is not yet complete.

The Subcommittee on Elevator Inspectors' Handbook held several meetings during the past year and its preliminary report is now being set in type prior to submission to the Sectional Committee for review and approval by letter ballot.

The Sectional Committee on a Safety Code for Mechanical Power Transmission Apparatus completed its original code in 1923. In 1927 it was slightly revised and given the status of an "American Standard" by the American Standards Association. On October 8, 1929, the Sectional Committee met to discuss a further revision of this Code in line with the work of its new Subcommittee on Mechanical Power Control, appointed in February, 1929.

No meetings of the Sectional Committee on a Safety Code for Conveyors and Conveying Machinery have been held since October

1, 1929. The work of the Committee has been carried on by correspondence but little progress has been made in further developing the four sections of the Code which are in preliminary form.

A meeting of the Sectional Committee on a Safety Code for Cranes, Derricks, and Hoists was held on January 21, 1930. The following three of its Subcommittees also met: Subcommittee No. 1 on Overhead and Gantry Cranes, January 20 and 21, 1930, Subcommittee No. 3 on Derricks and Hoists, March 24, 1930, and Subcommittee No. 5 on Jacks on November 6, 1929, and April 8, 1930. The Editing Committee is now correlating and editing the reports of Subcommittee No. 1 on Overhead and Gantry Cranes and Subcommittee No. 2 on Locomotive and Tractor Cranes.

The Safety Committees on which the Society has representation are as follows:

Safety Code Correlating Committee
Sectional Committee on Safety Code for Abrasive Wheels
Sectional Committee on Safety Code for Floor Wall Openings, Railings, and Toe Boards
Sectional Committee on Safety Code for Industrial Sanitation
Sectional Committee on Safety Code for Lighting Factories, Mills, and Other Work Places
Sectional Committee on Safety Code for Forging and Hot Metal Stamping
Sectional Committee on Safety Code for Ladders
Sectional Committee on Safety Code for Laundry Machinery and Operation
Sectional Committee on Safety Code for Logging and Sawmill Machinery
Sectional Committee on Safety Code for Aeronautics
Sectional Committee on Safety Code for Textiles
Sectional Committee on Underground Power Transmission and Power Equipment for Metal Mines
Sectional Committee on Safety Code for Machine Tools
Sectional Committee on Safety Code for Paper and Pulp Mills
Sectional Committee on Safety Code for Power Presses, and Foot and Hand Presses
Sectional Committee on Safety Code for Rubber Machinery
Sectional Committee on Safety Code for Walkway Surfaces
Sectional Committee on Safety Code for Amusement Parks
Sectional Committee on Safety Code for Window Washing
Sectional Committee on Safety Code for Color for the Identification of Gas Mask Canisters
Sectional Committee on Safety Code on Ventilation for Metal Mines
Sectional Committee on Safety Code on Ventilation in Coal Mines
Sectional Committee on Safety Code for Ventilation
Sectional Committee on Safety Code for Mechanical Refrigeration
Special A.S.A. Committee on Low Voltage Electrical Hazard.

Respectfully submitted,

HAROLD W. MOWERY, *Chairman*
JOHN PRICE JACKSON — ARTHUR M. TODE
LEW R. PALMER — THOMAS A. WALSH.

POWER TEST CODES

The Committee on Power Test Codes presents the following report for the year ending September 30, 1930.

TEST CODES COMPLETED

During the year three of the original Codes in the series of twenty-four test and supplementary codes were completely revised in the light of current practice and reprinted in pamphlet form. These were the Code on General Instructions and the Test Codes for Stationary Steam-Generating Units and Internal-Combustion Engines.

Twenty of the twenty-four test and supplementary codes and four of the thirty-seven sections of Instruments and Apparatus have been completed and published during the period 1922–1930 as follows:

Code on General Instructions
Code on Definitions and Values
Test Code for Solid Fuels
Test Code for Liquid Fuels
Test Code for Stationary Steam-Generating Units
Test Code for Reciprocating Steam Engines
Test Code for Steam Turbines
Test Code for Reciprocating Steam-Driven Displacement Pumps
Test Code for Centrifugal and Rotary Pumps
Test Code for Displacement Compressors and Blowers
Test Code for Feedwater Heaters
Test Code for Condensing Apparatus
Test Code for Atmospheric Water-Cooling Equipment
Test Code for Refrigerating Systems
Test Code for Evaporating Apparatus
Test Code for Steam Locomotives
Test Code for Gas Producers
Test Code for Internal-Combustion Engines
Test Code for Hydraulic Power Plants and Their Equipment
Test Code for Speed-Responsive Governors
Instruments and Apparatus:
Part 1, General Considerations
Part 2, Pressure Measurement
Chapter 1, Barometers
Chapter 6, Tables, Multipliers, and Standards for Barometers, Mercury Columns, and Pressure Measurements
Part 21, Leakage Measurement
Chapter 1, Condenser Leakage Tests

Two new test codes were completed within the year, namely, the Test Codes for Liquid Fuels and Atmospheric Water-Cooling Equipment. Both of these Codes were approved and adopted by Council as the standard practice of the Society in August and September, 1930, respectively. The Test Code for Liquid Fuels appeared in the December, 1929, issue of *Mechanical Engineering* and in December, 1929, at the Annual Meeting of the Society it was presented for discussion at a Public Hearing. The final revision of the proposed Code was based on the criticisms and comments received at this hearing.

In the January, 1930, issue of *Mechanical Engineering* the Test Code for Complete Steam-Electric Power Plants was published. This Code was then presented for discussion at a Public Hearing held in Detroit in June, 1930, and is now receiving its final revision by Individual Committee No. 11 on Complete Steam Power Plants.

Due to the extensive revision of the Test Code for Stationary Steam-Generating Units to cover certain important changes made necessary by present boiler practice, an abstract of the revised draft was published in the November, 1929, issue of *Mechanical Engineering*. The criticisms and suggestions received were of considerable assistance to the Individual Committee in bringing the Code up to date before re-publication.

Considerable progress has been made in the development of the Test Code for Centrifugal and Turbo-Compressors and Blowers. In the preparation of this Code, Individual Committee No. 10 learned that the Prime Movers Committee of the National Electric Light Association planned to cooperate with the Fan Manufacturers Association in the preparation of a Code for the testing of fans after installation. The services of Individual Committee No. 10 were offered to this group in an attempt to bring about complete cooperation in the development of this proposed test code.

A résumé of the progress which has been made during the past year in the preparation of the various parts and chapters of Instruments and Apparatus is as follows: Part 3, Temperature Measurement, Chapter 5 on Pyrometric Cones, appeared in the August, 1930, issue of *Mechanical Engineering;* Part 11, Measurement of Quality of Steam, appeared in abstract form in the June, 1930, issue of *Mechanical Engineering;* Part 17, Determination of the Viscosity of Liquids, was published in the March, 1930, issue of *Mechanical Engineering;* the development of the following parts and chapters has progressed appreciably within the past year: Part 2, Pressure Measurement, Chapter 2 on Static and Total Pressure, Static Holes and Tubes, Impact Tubes; Part 3, Temperature Measurement, Chapter 5 on Pyrometric Cones, Chapter 6 on Liquid-in-Glass Thermometers, and Chapter 7 on Bourdon Tube Thermometers; Part 5 on Measurement of Quantity of Material; Part 6 on Electrical Measurements; Part 8 on Measurement of Indicated Horsepower; Part 9 on Heat of Combustion; Part 13 on Speed Measurement; Part 16 on Density Determinations; and Part 20 on Smoke-Density Determinations.

The publication of preliminary drafts of the Power Test Codes and other related material in *Mechanical Engineering* for the year has filled sixteen (16) pages.

PERSONNEL CHANGES

The Committee records with deep regret the deaths during the year of four of its members who have been active in the work of the Individual Committees: W. J. A. London, who was a member of Individual Committee No. 6 on Steam Turbines; R. D. Pratt, who served on Individual Committee No. 4 on Stationary Steam-Generating Units; and Messrs. Thomas Shipley and Peter

Neff, both of whom were members of Individual Committee No. 13 on Refrigerating Systems.

Several additions have been made by appointment to the Individual Committees: C. U. Savoye on Committee No. 4 on Stationary Steam-Generating Units, H. D. Kelsey on Committee No. 10 on Centrifugal and Turbo-Compressors and Blowers, and E. L. Lindseth on Committee No. 19 on Instruments and Apparatus. Following the resignation of N. A. Carle as Chairman of Committee No. 11 on Complete Steam Power Plants, R. J. S. Pigott, who has had an important part in the development of the proposed test code, was unanimously elected to succeed Carle as Chairman.

National Contacts

The Committee this year has corresponded with the American Gas Associations, the American Standards Association, and the Pacific Coast Gas Association relative to the setting up of a standard temperature and pressure of reference for gas measurement under varying conditions of service and test.

International Contacts

Within the year the Main Committee, with the assistance of Individual Committee No. 4 on Stationary Steam-Generating Units, reviewed the Italian Standard Specifications for the Thermal Tests of Boilers (1929) which had been submitted by the Italian National Standardizing body. The Committee's comments on the Code were appreciated by the Italian Committee.

A preliminary draft of the V.D.I. Test Code for Testing Oil and Gas Engines, Gas Generator, and Waste Heat Using Apparatus was referred to Individual Committee No. 17 on Internal-Combustion Engines for study and review.

International Electrotechnical Commission

The Society and the Main Committee on Power Test Codes, through membership on the U. S. National Committee of the International Electrotechnical Commission, have been actively engaged in assisting to bring about international agreements on acceptance tests for hydraulic and steam turbines and internal-combustion engines during the past five years. The U. S. National Committee of the I.E.C. holds the Secretariat for the Advisory Committees on these types of prime movers. The Society was represented this year on the U. S. National Committee by Fred R. Low, William F. Durand, Francis Hodgkinson, C. Harold Berry, and H. Birchard Taylor.

The fifth meeting of I.E.C. Advisory Committee No. 5 on Steam Turbines was held in Stockholm, Sweden, June 30–July 4, 1930, and by intensive work the following parts of the proposed I.E.C. Publication on Steam Turbines were completed and approved:

Part I Specifications

- Appendix A Information to be supplied with inquiry or order for steam turbines
- Appendix B Suggested standard ratings of steam turbines
- Appendix C Suggested standard boiler steam pressures
- Appendix D Graphical symbols for heat power systems.

Part II Rules for Acceptance Tests

- Section 1 Object and scope
- Section 2 Enumeration and description of terms
- Section 3 Guiding principles
- Section 4 Instruments and methods of measurement
- Section 5 Computation of results
- Section 6 Report of tests carried out in accordance with I.E.C. Rules for Acceptance Tests.

This material was transmitted to the Plenary Meeting of the Commission held in Oslo, Norway, on July 9, 1930, and received the final approval of this governing body of the International Electrotechnical Commission.

During the eight months prior to the meeting the Secretariat was engaged in preparing and editing the material which had been developed at the previous meetings, the original bases of which are the specifications or codes previously formulated by the interested engineering and industrial groups of certain of the ten member countries. At this 1930 meeting of Advisory Committee No. 5, Messrs. Francis Hodgkinson, Irving E. Moultrop, William L. Abbott, Geo. A. Orrok, Harvey N. Davis, Joseph H. Keenan, and Ely C. Hutchinson represented the U. S. National Committee, while C. B. LePage attended on behalf of the Secretariat.

The International Electrotechnical Commission, through the resolution of its Committee of Action, appointed Advisory Committee No. 19 on Internal-Combustion Engines in November, 1929. An invitation was extended to the U. S. National Committee to accept the responsibilities of the Secretariat. After due consideration this invitation was accepted in December, 1929, and Francis Hodgkinson was appointed Director of the Secretariat and C. B. LePage, Assistant Director.

Capitalizing the experience in this field gained by the A.S.M.E. Committee on Power Test Codes and by the I.E.C. Advisory Committee No. 5 on Steam Turbines, the U. S. National Committee in preparing for an organization meeting of Advisory Committee No. 19, drafted a proposal for Part II, Rules for Acceptance Tests of Internal-Combustion Engines. An additional document was also prepared by the Secretariat which consisted of the U. S. National Committee's comments on the proposal of the British National Committee for Part I, Specifications.

Two sessions of Advisory Committee No. 19 were held at Stockholm on Saturday, July 5, at which the six documents placed before it by the National Committees of Great Britain, Switzerland, and the United States were reviewed in a general way. Since this was the first meeting of the Committee, the discussion was of a preliminary nature. When the meeting adjourned, a general agreement had been reached as to the subjects to which the Committee would give its first attention in preparing for its next meeting. The U. S. National Committee was represented by Messrs. Francis Hodgkinson, H. C. Dickinson, Harvey N. Davis, Ely C. Hutchinson, and H. S. Osborne, while the Secretariat was represented by C. B. LePage.

The twenty Individual Committees and the Main Committee on Power Test Codes now include in their personnel 119 members of the Society and 12 non-members.

Respectfully submitted,

Fred R. Low, *Chairman*

C. Harold Berry	David S. Jacobus
Lester P. Breckenridge	Charles E. Lucke
Edwin H. Brown	Lionel S. Marks
Alexander G. Christie	Lewis F. Moody
Harte Cooke	Irving B. Moultrop
Paul Diserens	Henry B. Oatley
Robert H. Fernald	Geo. A. Orrok
Edwards R. Fish	Reginald J. S. Pigott
C. F. Hirshfeld	Edwin B. Ricketts
Francis Hodgkinson	Edward N. Trump
Ozni P. Hood	William M. White
George A. Horne	Walter J. Wohlenberg.

BOILER CODE

The Boiler Code Committee submits the following report for the fiscal year ending September 30, 1930:

During this period the Committee held nine regular meetings devoted to interpretations and to the consideration of revisions and addenda to the various sections of the Code. The meetings continue to be of marked importance to the states, municipalities, and the boiler- and pressure-vessel industry. With the recent developments in this field, many questions of vital nature are submitted. The service rendered to the public in this manner is of incalculable value in providing for new developments and practice along various lines of advance.

Cooperation with the American Society for Testing Materials is still carried on to the advantage of the industry. During the year new Specifications have been adopted by the A.S.T.M., covering Arbitration Test Bar and Tension Test Specimen for Cast Iron, and have been accepted by the Boiler Code Committee for incorporation in the Code. In addition, in order to make the Material Specifications Section of the Code conform more closely with the A.S.T.M. Specifications, the style and general arrangement of the Specifications as they appeared in the 1927 edition of the Code have been rearranged so that they are identical with that of the A.S.T.M. This will prove of assistance in comparing the Specifications with those of the A.S.T.M.

The Committee has made numerous revisions of the various sections of its Code as a result of requests from manufacturers, inspectors, users, and others. These revisions include rules to cover any series of holes that may be placed longitudinally in a drum without reinforcement, rules for the reinforcement of manholes and other openings, and rules for riveted and welded nozzles. They also include rules for the more extensive use of fusion welding on power boilers and the extension of the pressure and diameter limitations for fusion-welded unfired-pressure vessels, provided that the Recommended Procedure is followed. These revisions were formally adopted by the Council and distributed in pink-colored addenda sheets on August 12, 1930. It is the Committee's understanding

that these revisions, while now acceptable in the various states and cities in which the Boiler Code has been adopted as their Standard and is operative, will not become mandatory until January 1, 1931, thereby allowing a reasonable period of grace after they are announced.

The Sub-Committee on Welding has actively cooperated with the Conference Committee of the American Welding Society. Proposed Specifications for the Fusion Welding of Drums or Shells of Power Boilers were published in the March, 1930, issue of *Mechanical Engineering*. The large amount of discussion received on these Proposed Specifications is an evidence of the great interest shown in the subject of fusion welding by engineers at large. Symposiums for the presentation and discussion of these specifications were held during the year by the American Welding Society and the National Board of Boiler and Pressure Vessel Inspectors. As a result it was brought out that there was an urgent need for similar specifications for the Code for Unfired Pressure Vessels to allow vessels covered by the Code to be fusion welded without limit as to dimensions or working pressures. The Committee therefore drafted such a set of specifications, which will soon appear in *Mechanical Engineering* for public comment. In addition to the latter specifications it is intended to further extend the scope of the rules covering unfired pressure vessels which may be fusion welded without being stress relieved.

The need has been shown for a list of official Interpretations of the Committee which can be considered inactive or obsolete as a result of revisions of Code rules that incorporate the basic ideas thereof. The number of interpretations is steadily increasing, and manufacturers have been put to considerable inconvenience in keeping track of the Cases which may still be considered active. This matter is being considered by the Committee, and as soon as this investigation has been completed, the list will be generally distributed.

Tests are being carried on by the Taylor Forge and Pipe Company, Chicago, Ill., with a view to presenting data to permit of amplifying the rules for nozzle and dome reinforcements that now appear in Pars. P-268 and U-59 of the Code.

The question of the use of fusion welding on calking edges of riveted joints is one which has been before the Committee for some time. The matter had been referred to the Conference Committee of the American Welding Society, but when the report was received, it was found that sufficient information concerning penetration of the weld was not presented. The matter is being given further consideration by the Subcommittee on Welding with a view to presenting a recommendation for incorporating a rule in the Code.

The Committee has been and is still actively cooperating with local groups in Oklahoma regarding the status of the Code for Unfired Pressure Vessels and its application to the conditions encountered in the petroleum field. Reports have been received from time to time to the effect that the petroleum interests, tank manufacturers, and others interested in the Mid-Continent oil fields, had under consideration the formulation of a Code to suit their particular needs, and as a result the Committee has actively endeavored to obtain the consideration of these interests of the Society's Code. Conferences between some of the members of the Committee and those interested have helped considerably toward the realization of the advantages to be gained in using our Code, and the facts at the present time warrant the statement that this matter will eventually be settled satisfactorily.

The Committee wishes to report cooperation with the Canadian Provincial boiler inspectors. As a result of the attendance of the Honorary Secretary of the Boiler Code Committee at the conference held at Calgary, Canada, in May, it was learned that these inspectors were much interested in the A.S.M.E. Code. The Heating Boiler and Unfired Pressure Vessel Sections of the A.S.M.E. Code were adopted at the conference almost in their entirety for use in Canada.

Messrs. W. A. Nevin and J. W. Turner have been appointed members of the Subcommittee on Heating Boilers. In recognition of the service of Charles S. Blake who has resigned as member and Chairman of the Sub-Committee on Rules for Inspection, he was appointed as Honorary Chairman and John A. Collins was appointed as member and Chairman in his place. V. M. Frost was appointed a member of the Executive Committee. H. B. Oatley was appointed a member of the Boiler Code Committee. Honorary membership on the Boiler Code Committee was conferred on Charles L. Huston upon severing his active connection after many years' service.

The Committee reports with deep regret the deaths of its Honorary Chairman, John A. Stevens, on November 18, 1929, of Messrs. S. F. Jeter, a member of the Committee, on December 31, 1929, and W. P. Eales, a member of the Subcommittee on Rules for Inspection, and Pennsylvania representative on the Conference Committee, on January 25, 1930.

Respectfully submitted,

F. R. Low, *Chairman*
D. S. Jacobus, *Vice-Chairman*
C. W. Obert, *Honorary Secretary*
H. E. Aldrich
W. H. Boehm
F. S. Clark
F. W. Dean
W. F. Durand
E. R. Fish
V. M. Frost
C. E. Gorton
A. M. Greene, Jr.
F. B. Howell
J. O. Leech
LeRoy Mikels
E. F. Miller
M. F. Moore
I. E. Moultrop
C. O. Myers
H. B. Oatley
James Partington
C. L. Warwick
H. LeRoy Whitney.

PROFESSIONAL CONDUCT

During the fiscal year 1929-1930, the Society received one complaint of unprofessional conduct on the part of two members of the Society. This was referred to the Committee on Professional Conduct which decided that no official action should be taken.

The Secretary of the Society took care of three requests for advice on professional ethics.

Respectfully submitted,

John Hunter, *Chairman*
D. R. Yarnall
W. B. Powell
A. G. Christie
H. S. Philbrick.

Fiftieth Anniversary Celebration

THE Fiftieth Anniversary Celebration of The American Society of Mechanical Engineers brought together from Europe, Asia, Africa, Australia, and North and South America, distinguished engineers who testified to the economic and social effects of engineering and science on the progress of civilization in the countries which they represented. The testimony was impressive and authoritative.

The anniversary was memorable on account of its international atmosphere and the dominance of a spirit of progress, and because of the historical significance of the exercises in New York and in Hoboken.

The celebration was officially opened on Saturday morning, April 5, with the unveiling in the lobby of the Engineering Societies Building of a memorial tablet commemorating the Fiftieth Anniversary of the Society. The tablet, a very beautiful piece of memorial art, conceived and modeled by Julio Kilenyi, shows the engineer symbolized by a man of powerful physique gazing past some typical measuring instruments, indicative of this fundamental function of his technique, into the future, the plans for which are shown as being already within his grasp. This design had been adapted from the Fiftieth Anniversary Medal, also designed by Julio Kilenyi.



THE FIFTIETH ANNIVERSARY MEDAL

The presiding officer upon the occasion of the unveiling was Charles E. Gorton, vice-president of the Society, and the presentation address was made by Charles T. Main, a past-president. Francis Lee Stuart made a very gracious and feeling speech of acceptance for the Engineering Foundation, Inc. The actual unveiling was done by John Sweet, a grand-nephew of John E. Sweet, a founder and past-president of the Society.

Registration had started on the preceding afternoon and delegates had presented their credentials. The anniversary badges were replicas in bronze of the Fiftieth Anniversary Medal, which in turn repeated in medal form the motif on the official tablet. These medals were hung on various combinations of blue and gold ribbon that identified their wearers respectively as delegates, medalists, guests, and members of the staff.

McGraw-Hill Commemorative Exercises

The first of the events of historical significance was conducted under the auspices of the McGraw-Hill Publishing Co., Inc., and commemorated the part played by the *American Machinist* in the founding of the A.S.M.E. Transported by buses from the Engineering Societies Building to the McGraw-Hill Building, at 36th Street and 10th Avenue, New York, the party was then conducted to the thirteenth floor, where the ceremonies took place.

Kenneth Condit, editor of the *American Machinist*, acted as chairman for the occasion and introduced Malcolm Muir, president of the McGraw-Hill Publishing Co., Inc., who delivered the address of welcome. William Elmer, vice-president of the A.S.M.E., made the acknowledgment for the Society.

On a stage which had been erected at one end of the room was enacted a one-act play, "Just Before an Interesting Event" or "What Might Have Happened in the Office of the *American Machinist* Three Days before the Preliminary Meeting."

The scene showed the interior of the office of the *American Machinist* at 96 Fulton Street, on the morning of February 13, 1880. As the curtain rose, the bookkeeper, played by A. J. McElhone, entered and started a fire in the Franklin stove. He was followed by Jackson Bailey, editor of the *American Machinist*, played by Ralph S. Foss, and later by Horace B. Miller, publisher, played by William Chevalier. A conversation between Bailey and Miller eventually developed into a discussion of how best to bring together some engineers to discuss in an amicable manner the desirability of forming an association of mechanical engineers. As an enterprising publisher of an engineering journal, Mr. Miller was eager to take a position of leadership, and the happy thought of giving a dinner at the Astor House to pave the way for a settlement of possible differences caused him to dispatch a copy boy, played by Harry Erickson, to the hotel with a letter making arrangements for the dinner. History has it that the dinner accomplished its purpose, for after it, on February 16, 1880, the decision was reached to call the historic meeting of April 7 at Stevens Institute, at which the A.S.M.E. was founded.

Following the presentation of this play, a telegram of greeting from James H. McGraw was read. Roy V. Wright, past-vice-president of the Society, offered a motion of thanks and acknowledgment, which was heartily applauded and adopted. A delightful luncheon was served and there was ample opportunity for visiting and exchanging greetings. Copies of the anniversary issue of the *American Machinist*, a beautiful book, well illustrated, depicting the history of the Society and the corresponding advances in the engineering profession since 1880, were distributed. Accompanying this issue there was also a

reprint of the *American Machinist* of fifty years ago which announced the preliminary meeting for the discussion of the formation of an association of mechanical engineers.

The Pageant at Stevens Institute

After luncheon the party was taken by buses across the river to Stevens Institute of Technology in Hoboken, N. J., where a pageant, called "Control," written and directed by George Pierce Baker, director of the department of drama of Yale University, assisted by Harold Burris-Meyer, of Stevens, was presented. The cast was composed of students of the Institute.

The pageant was held in the auditorium of Stevens Institute because it was there that the original meeting of the Society convened. Symbolic figures, motion pictures, and well-acted scenes were used to illustrate the development of mechanical engineering during the past fifty years.

The theme of the pageant was developed through five main scenes, dealing with Watt and Boulton and the steam engine; Stephenson, and his railroad from Liverpool to Manchester over Chat Moss bog; Faraday's experiment in magneto-electric induction; the organization meeting of the A.S.M.E. on April 7, 1880; and Edison's first demonstration of electric lights.

The complete text of the pageant has been published in book form by the Society.

The Welcoming Dinner

On Saturday evening at the Hotel Roosevelt was held the Welcoming Dinner under the auspices of the Metropolitan Section of the Society. The toastmaster was Charles M. Schwab, past-president of the Society. The address of welcome was given by Col. Paul Doty, vice-president of the Society. Other speakers of the program included Edward J. Mehren, vice-president of the McGraw-Hill Publishing Co., who spoke as a representative of the engineering press, and Robert I. Rees, president of the Society for the Promotion of Engineering Education, who brought a message from the engineering educators of the country. The attendance exceeded 800.

Commemorative Services

On Sunday commemorative services were held at the Cathedral of St. John the Divine. The official party upon this occasion was headed by Robert L. Daugherty, vice-president of the Society.

At 3.50 p.m. the A.S.M.E. special train left for Washington with the official party, arriving there at 8.30.

Welcoming Assembly

The headquarters in Washington was at the Mayflower Hotel, and as in New York, the first order of the day was registration, the presentation of credentials, and the distribution of badges.

At 10 a.m. the welcoming assembly was held in the flag-draped National Council Chamber of the U. S. Chamber of Commerce Building, a few blocks from headquarters. Ralph E. Flanders, vice-president of the Society, presided.

Mr. Piez, president of the Society, whose illness prevented his attendance, was represented by the six vice-presidents of the Society, Paul Doty, William Elmer, Conrad N. Lauer, Robert L. Daugherty, Charles E. Gorton, and Mr. Flanders.

Mr. Flanders spoke feelingly of the absence of President Piez. He then reminded his audience of the death of Chief Justice Taft, of his splendid and fearless life, and of the remembrance that the Society would always have of his address to them in 1917, and asked that all stand for a moment in honor of his memory.

In welcoming the delegates in the name of the Society, Mr. Flanders assured them of the appreciation with which their greetings were received. He then turned the meeting over to the Secretary of the Society, Calvin W. Rice, who introduced the delegates from engineering organizations both of other countries and of our own, who brought greetings and addresses from their fellow-engineers. A complete list of all delegates will be found at the end of this account. The countries and their representatives were as follows:

Australia, A. H. Chapman
Austria, Adolf Giesl-Gieslingen
Belgium, Albert de Smaele
Canada, Alexander J. Grant
Colombia, Julio Garzon Nieto
Denmark, A. C. Gronbeck
France, Georges Claude
Germany, Karl Maybach
Great Britain, William Henry Patchell
Japan, A. Ouchi
Mexico, Norberto Dominguez
Netherlands, Auguste Plate
Norway, Bjarne Johnsen
Union of South Africa, Wesley Ernest John
Sweden, Vilhelm Nordström
Switzerland, Henry A. Naville
Turkey, L. A. Scipio

Cuba's delegate was not present, but sent greetings by telegraph. Czechoslovakia's greetings were given by the Czechoslovakian minister. Senator Luiggi, who was to have brought Italy's greetings but unfortunately was taken ill upon his arrival, was unable to attend any of the sessions, at which universal regret was expressed.

Greetings from the engineering organizations in the United States were brought by Francis Lee Stuart, representing the American Society of Civil Engineers, by William H. Bassett, president of the American Institute of Mining and Metallurgical Engineers, and by Harold B. Smith, president of the American Institute of Electrical Engineers.

The engineering colleges in the United States were represented by Palmer C. Ricketts, president of Rensselaer Polytechnic Institute, while Admiral David W. Taylor presented the greetings from the scientific and professional societies in the United States. The business organizations of the United States had for their spokesman William Butterworth, president of the United States Chamber of Commerce.

The beautifully engrossed greetings and elaborately illuminated scrolls brought by the delegates and representatives were later put on display in the Chinese Room of the Mayflower Hotel, and were the object of much admiration throughout the meeting.

Humanistic Aspects of Engineering

Sixteen monographs had been prepared covering the social and economic effects of engineering upon the lives of the people represented by the distinguished engineers who had been chosen to receive the Fiftieth Anniversary Medal which had been struck in memory of the occasion.

Charles E. Gorton, vice-president of the A.S.M.E., acted as chairman at the first session for the presentation of the addresses summarizing the monographs.

These summarizing addresses were outlined in the account of the Fiftieth Anniversary celebration published in the May, 1930, issue of *Mechanical Engineering*. The complete monographs are to be published in book form. The names of those who prepared the monographs and presented the addresses are given in the following paragraphs.

The Austrian monograph was edited by Hofrat Ing. Ludwig Erhard, director, Technical Museum, Vienna, and president of the Oesterreichischer Verein deutscher Ingenieure. The co-editors were Prof. Ing. Josef Fugiewicz, mining, Prof. Dr. Ing. Othmar Keil-Eichenthurm, foundry, General Direktor Ing.

Friedrich Brock, power management, Sektionschef Ing. Bruno Enderes, communication, Oberbaurat Ing. Ernst Stelzer, technology, and Sektionschef Ing. Otto Kunze, technical institutions. Ing. Dr. Adolf Giesl-Gieslingen made the summarizing address.

The Belgian monograph was prepared by a group consisting of The Honorable Georges Theunis, Minister of State, Dr. Edouard Gosselin, professor of physics at the Military School of Belgium, Prof. Edouard W. Bogaert, University of Brussels, and Chief Engineer of the Marine, Prof. Gommaire Von Engelen, University of Ghent, Prof. Chas. Hanocq, University of Liége, Prof. Gustave Gillon, University of Louvain, and Prof. René J. Bradfer, School of Mines and Metallurgy at Mons. The summarizing address was presented by Dr. Albert de Smaele.

The Canadian monograph was presented in abstract by its author, Brigadier-General Charles H. Mitchell, Dean, Faculty of Applied Science and Engineering, University of Toronto, and Past-President, Engineering Institute of Canada.

Ing. Dr. h. c. Emil Zimmler, President, Masaryk Academy of Work, contributed the Czechoslovakian monograph, and Dr. Josef Z. Schneider presented the address summarizing it.

The address summarizing the French monograph was presented by Georges Claude, inventor and scientist. This memorial of engineering achievements in France was divided into chapters, each one of which had been edited by an outstanding specialist so that it might be as complete and as exact a document as possible. The authors were Maurice Michel-Schmidt, public works; Louis Breguet, aviation; Charles de Fréminville, the automobile; General Gustave Ferrié and Professor André Blondel, wireless telegraphy; Albert M. G. R. Portevin and M. Galibourg, metallurgy; Casimir Moteil, motors; Professor Denis Eydoux, hydraulics; Pierre Parent, mines; Professor Paul Boucherot, electrical engineering; Maxime Laubeuf, ships; Arsène d'Arsonval and M. Billardon, refrigeration; and Professor Camille Matignon and M. Montier, railways.

Dr. Ing. Conrad Matschoss, director of the Verein deutscher Ingenieure, author of the German monograph, delivered the address summarizing it.

The British monograph was summarized in an address by its author, Mr. Loughnan St. L. Pendred, president of the Institution of Mechanical Engineers and editor of *The Engineer* (London).

Prof. Dr. Ing. Luigi Luiggi, Senator, Kingdom of Italy, honorary member of the American Society of Civil Engineers, and member of the Institution of Civil Engineers, was the author of the Italian monograph. Although Senator Luiggi had come to this country especially to present the address summarizing his monograph, he was detained in New York on account of illness and his address was read Tuesday morning by C. E. Davies, assistant secretary, A.S.M.E.

Dr. Masawo Kamo, head of the department of mechanical engineering, Tokyo Imperial University, president of the Society of Mechanical Engineers of Japan, and honorary member of The American Society of Mechanical Engineers, was the author of the Japanese monograph and made the address summarizing it.

The presentation of the monographs covering the humanistic aspects of engineering was continued on Tuesday morning, with William Elmer, vice-president of the A.S.M.E., presiding.

Senor Ing. Norberto Dominguez presented the summarizing address of the Mexican monograph, of which he was the author.

The monograph devoted to engineering in The Netherlands was written by Prof. Ir. Daniel Dresden, president of the Jaffa Engine Works, who also presented the address summarizing it.

Vilhelm Nordström, manager of the De Laval Steam Turbine Company, Sweden, delivered the address summarizing the monograph from the Scandinavian countries. Mr. Nordström's collaborators in writing the monograph were Ing. Povl Vindig, past-president, Danish Engineering Society, Denmark; Ing. Prof. B. Wuolle, professor of industrial economy, Technical University of Helsingfors, Finland; and Ing. Reidar Lund, consulting engineer, Norway.

The Colombian monograph was written by Prof. Julio Garzon Nieto, chief engineer for the Ministry of Foreign affairs, who presented it in abstract.

The monograph on engineering in the southern countries of South America was written by Prof. Donato Gaminara, of Uruguay. The address summarizing it was delivered by Dr. L. S. Rowe, director-general of the Pan-American Union, Washington, D. C.

The chief editor of the Swiss monograph was Prof. Dr. Aurel Stodola, Grashof Medalist of the Verein deutscher Ingenieure. The collaborators in preparing the monograph were Prof. Dr. B. Bauer, electrotechnology; Prof. Dr. E. Böhler, political economy; Dr. h. c. E. Huber-Stockar, railways; Prof. E. Meyer-Peter, hydraulics; and Prof. Dr. W. Wyssling, power development. Henry A. Naville, of the Brown-Boveri, presented the summarizing address.

For the United States, Dr. Carl E. Grunsky, consulting engineer, president of the American Engineering Council and past-president of the American Society of Civil Engineers, delivered an address in which he summarized the monograph which he had written on the influences of engineering in this country. Following Dr. Grunsky, Dr. Fred R. Low, past-president of the A.S.M.E. and editor-emeritus of *Power*, presented "A Half-Century of Progress in Mechanical Engineering in the United States," a group of reports prepared by the Professional Divisions of the A.S.M.E. and their representatives.

The Founders' Luncheon

On Tuesday noon, at the Mayflower Hotel, a luncheon was served at which special medals were presented to the six living founder members of the Society; Ambrose Swasey, Robert F. Grimshaw, John S. Coon, Francis H. Richards, John W. Cloud, and Eugene H. Robbins. These medals were identical with the Fiftieth Anniversary Medal except that the inscription on the obverse had been changed to make the medal appropriate to the occasion. John R. Freeman, past-president of the Society, acted as chairman of the ceremonies of presentation, and Prof. Robert L. Daugherty, vice-president, presented the medals and the certificates which accompanied them. Of the six living founder members, Ambrose Swasey and Robert Grimshaw were the only ones at the luncheon. Mr. Swasey and Mr. Grimshaw made brief addresses in response to the applause that greeted them when the medals were awarded.

The medals awarded to the other four were received in their absence by well-known members of the Society, Edward N. Trump representing Mr. Coon, George Bond representing Mr. Richards, Prof. Wm. T. Magruder representing Mr. Cloud, and Dean R. L. Sackett representing Mr. Robbins.

The Conferring of Honors

The most impressive session of the Fiftieth Anniversary Celebration was the convocation for the conferring of honors held on Tuesday afternoon in the National Council Chamber of the United States Chamber of Commerce Building. These exercises were made memorable not only because of the distinguished engineers who were to receive the awards, but also because of the fact that the chief diplomatic officer of each country presented to the Society for the conferring of the Fiftieth Anniversary Medal the engineer selected for this honor by the engineering profession of his country.

The marshals for the occasion, appropriately robed, escorted the medalists and the ambassadors from the reception room at

the right of the stage to seats in the front of the room. The marshals were the members of the Society's committee on awards: Kenneth H. Condit, Arthur M. Greene, Jr., Herbert L. Seward, and Roy V. Wright. On the stage were Conrad N. Lauer, vice-president of the Society, who acted as chairman and presented the medals, Dr. Wm. F. Durand, president, Guggenheim Medal Board, L. P. Alford, chairman of the Gantt Medal Board, and C. E. Davies, assistant secretary of the Society.

The Fiftieth Anniversary medals were presented first. The ambassador or other diplomatic officer of the country represented by the medalist, and the medalist were escorted to the platform by the marshals, the ambassador approaching from the right of Mr. Lauer, and the medalist from his left. The ambassador was then presented to Mr. Lauer, and in turn presented the medalist. Mr. Lauer then delivered a brief address citing the distinguished achievements of the medalist and presented him with the Anniversary Medal in bronze. A gold replica of the medal was then pinned to the medalist's coat and the party left the stage. The same procedure was followed in presenting the Daniel Guggenheim Medal, the Gantt Gold Medal, the A.S.M.E. Medal, and the Melville Medal, with the exception that Dr. Durand presented the Guggenheim Medal and L. P. Alford the Gantt Medal. A list of the medalists follows.

A.S.M.E. Fiftieth Anniversary Medalists

Austria. Hofrat Ing. Ludwig Erhard. Represented by His Excellency Edgar L. Prochnik, Minister to the United States.

Ludwig Erhard is director of the Technical Museum in Vienna, honorary member of the Technical University of Vienna, and president of the Oesterreichischer Verein deutscher Ingenieure. He was born at Passau, Bavaria, in 1863, and attended the Technical University at Munich. He engaged in mechanical-engineering work for several years, was at the head of the Bavarian Museum for Industry and Craft in Vienna, and technical director of the Austrian Institute for the Promotion of Craft of the Chamber of Trade, Craft, and Industry in Vienna. The Technical Museum in Vienna, one of the world's great museums, owes its prominence to the work of Erhard, a most notable achievement.

Belgium. To the Fédération des Associations Belges d'Ingénieurs, under whose auspices the monograph for that country was prepared.

Bronze medals were presented to the authors. Baron Gaston S. P. de Bethune represented the Fédération at the Anniversary. He was presented by Vicomte de Lantsheere, Chargé d'Affaires, Belgian Embassy.

Canada. Brigadier-General Charles H. Mitchell. Presented by His Excellency Vincent Massey, Minister to the United States.

Charles Hamilton Mitchell, dean of the Faculty of Applied Science and Engineering of the University of Toronto since 1919, president of the Engineering Institute of Canada for 1929, and the recipient of many military honors, was born at Petrolia, Ontario, Canada, in 1872. He received the degrees of B.A.Sc., C.E., and honorary L.L.D. from the University of Toronto, served as city engineer of Niagara Falls, N. Y., as engineer for the Ontario Power Company of the same city, and conducted a consulting practice in Toronto for several years. He has had an outstanding military career and has received many honors including the D.S.O., C.M.G., and C.B. He is an officer of the Legion of Honor, France, Order of the Crown of Italy, and Order of Leopold, Belgium, and has been given the Croix de Guerre, Belgium, and the Croce di Guerra, Italy.

Colombia, S. A. Prof. Julio Garzon Nieto. Presented by The Honorable José M. Coronado, Chargé d'Affaires, Colombian Embassy.

Julio Garzon Nieto, civil engineer and since 1910 chief engineer of the Office of Longitudes of the Ministry of Foreign Affairs of Colombia, received diplomas from the Catholic University of Bogota in 1882 and from the National University of Colombia in 1887, and also a degree from Rensselaer Polytechnic Institute, Troy, N. Y., in 1894. He served for some time as professor in the Colegio Mayor de Nuestra Sonora del Rosario, in the National Lyceum, in the Artisans' Institute, and as a member of the faculty of Mathematics and Engineering in the National University of Colombia. He then went into engineering work and served first as chief engineer of public works of the Department of Cundinamarca and as engineer of the Girardot Railway. He has done notable work in connection with the adjustment and settlement of boundaries in South America. In 1900–1901 he was sub-chief engineer of the Colombian delegation engaged in the adjustment of the boundary between Colombia and Venezuela. In 1911 he was chief engineer for Colombia on the joint commission for determining the Colombian-Venezuelan boundary. He also was chief engineer of the Colombian delegation for the settlement of the boundary with Equador. Later, he was technical adviser of the Colombian Legations in Spain and in Switzerland during the arbitration with Venezuela from 1918 to 1922; and was chief engineer of the Colombian delegation for the settlement of the boundary with Venezuela during the work of the commission of Swiss experts who as arbitrators determined the definite delineation of the frontier with Venezuela in 1922–1923.

Czechoslovakia. Dr. Stan. Špaček. Represented by His Excellency Ferdinand Veverka, Minister to the United States.

Dr. Špaček, of Prague, civil engineer experienced in construction, railroad and highway engineering and reclamation service, and an authority on economics in relation to these phases of engineering, was born in Slepotice, Czechoslovakia, in 1876, and received his engineering training and degree at the Technical University in Prague. He was engaged from 1902 to 1920 in railroad service, on highway development, and on irrigation and land reclamation projects in connection with the improvement of agriculture in his country. He served in the technical attaché service in Prague, and became general secretary of the first International Congress for Scientific Management, in Prague. In 1929 Dr. Špaček was appointed chief of Section E for Technical Economics in the Ministry of Public Works in Prague. He is also Honorary Docent of Technical Economics on the faculty of the Technical University in Prague. He is an honorary member of the Society of Industrial Engineers, Chicago, and of the Association of Friends of the Masaryk Academy of Work, Prague.

France. M. Georges Claude. Presented by His Excellency Paul Claudel, Ambassador to the United States.

Georges Claude, scientist and inventor, was born in 1870. He devoted many years to research, invention, and new ways of producing materials for industrial application, especially the liquefaction of air and of oxygen and hydrogen, the production of nitrogen and ammonia, and the industrial use of the new rare gases, argon, neon, and helium. One of his earliest achievements was the invention of the process in which acetylene is dissolved and stored under pressure in acetone, and which has made acetylene available for many uses in other countries as well as in France.

He made possible the production of pure oxygen by fractional distillation and rectification, on a scale that permits its use in industry. In 1914 he developed the liquid-oxygen bomb. Through years of work (1900–1914) he developed a process of producing pure nitrogen, and later (1918–1925) another for the fixation of nitrogen by synthesis of ammonia under high pressure. In connection with this synthesis he accomplished the preparation of hydrogen by liquefaction and distillation. He has developed the transformation of ammonia with a view to its use as fertilizer, by starting with sylvinite, and this has been accomplished with a correlative production of carbonate of soda. The industrial separation of the gases, argon, helium, and neon from the air was the subject of research and investigation by Mr. Claude during the years 1907 to 1928. He conceived and developed the neon light. At the present time he is engaged in investigations relating to the industrial extraction of thermal energy from the sea, the successful achievement of which will be of great importance.

Germany. Prof. Dr. Ing. Conrad Matschoss. Presented by His Excellency Friedrich W. von Prittwitz und Gaffron, Ambassador to the United States.

Conrad Matschoss, Director of the Verein deutscher Ingenieure (Society of German Engineers), and promoter of engineering interests and technical education in Germany, was born in 1871 at Neutomischel (Posen). After attending high school he studied engineering at the Technical University of Hanover. From 1898 to 1906 he taught mechanical engineering in the State College of Engineering at Cologne. In 1906 he became associated with the Verein deutscher Ingenieure as a member of the editorial staff of the society's publications. During the next two years he also completed his work on the "Development of the Steam Engine," and in 1908 it was published in two-volume form under the auspices of the society. Under his editorship the society then initiated the series of annual publications entitled "Beitrage zur Geschichte der Technik und Industrie"

(Contributions to the History of Engineering and Industry), of which nineteen volumes have appeared. Another work was one on the German hydraulic laboratories. Dr. Matschoss has also edited a series of books on behalf of the German Museum. Since 1909 he has lectured on the history of engineering at the Technical University, Berlin, in addition to his other duties.

Great Britain. MR. LOUGHNAN ST. L. PENDRED. Presented by His Excellency Sir Ronald Lindsay, Ambassador to the United States.

Loughnan St. L. Pendred, editor of *The Engineer* (London) and President, 1930–1931, of the Institution of Mechanical Engineers, was born in 1870. He received his technical education at the City and Guilds of London Institute, South Kensington, and the Technical College, Pinsbury. Mr. Pendred then indentured himself as an apprentice to James N. Paxman, head of Davey, Paxman and Company, Ltd., of Colchester. Finishing his time there, he went to Ghent in Belgium, where he spent some months in the works of Van den Kerchove and then went to the Chemin de Fer de l'Ouest, now the French State Railways, where he worked both in the railway shops and the office. On his return from France he entered the Ordnance Department of Sir W. G. Armstrong, Whitworth and Company, Ltd. He joined the editorial staff of *The Engineer* in 1896.

Italy. PROF. DR. ING. LUIGI LUIGGI. Represented by His Excellency Giacomo de Martino, Ambassador to the United States.

Dr. Luiggi, Senator of the Kingdom of Italy, honorary president of the National Council of Public Works of Italy, consulting engineer for harbors, rivers, and canals, member of international commissions on navigation works, was born in Genoa in 1856. He attended the University of Genoa, took his degree in civil engineering at the Royal University of Turin in 1878, pursued a special course in harbor engineering in the principal English ports for a year, and at the present time is professor of harbor engineering at the University of Rome. In 1896 the Argentine Government invited Dr. Luiggi to take charge of harbor works at Bahia Blanca, where he carried out extensive constructions, including graving docks, piers, barracks, and other buildings, and batteries. Later he built a system of lighthouses and semaphoric and telegraph stations along the coast of Patagonia; he also served as consulting engineer for new harbor works at Buenos Aires, Rosario, and Montevideo, and on inland irrigation works. In Africa, Dr. Luiggi prepared plans for the improvement of two harbors on the Red Sea, and was entrusted by the Italian Government with projects and works in the harbors of Tripoli and other cities. Since 1913 he has been a member of the International Committee for the Suez Canal, and of the European Commission for the Navigation of the Danube. In 1923, for the Egyptian Government, he prepared plans for the improvement of the harbors of Suez and Alexandria, and in 1926 planned other Egyptian works. He has also been consulted by the Greek and the Albanian governments.

Japan. DR. MASAWO KAMO. Presented by His Excellency Katsuji Debuchi, Ambassador to the United States.

Dr. Kamo, head of the Department of Mechanical Engineering of Tokyo Imperial University, member of the engineering standards committee of the Japanese government, and president of the Society of Mechanical Engineers of Japan, was born in Tokyo in 1876. He was educated at the Tokyo Imperial University and Engineering College, receiving the degrees of M.E. and Doctor of Engineering. Later he studied thermodynamics and applied mechanics in England and Scotland, and for three years made a special study of steam turbines and refrigerating machinery in the United States. Dr. Kamo has been on the faculty of Tokyo Imperial University since 1898, and head of its department of mechanical engineering since 1912. As professor of mechanical engineering he has held the chair of thermodynamics and steam turbines; he has also been a lecturer on cold storage and refrigeration on the Faculty of Agriculture, and on outlines of engineering industry on the Faculty of Economics. In addition to his service in standardization work in Japan, Dr Kamo designed the machinery departments for the first turbine steamers in Japanese waters, and for the training ship of the Japanese Nautical College.

Mexico. SEÑOR ING. NORBERTO DOMINGUEZ. Presented by His Excellency Manuel C. Téllez, Ambassador to the United States.

Norberto Dominguez, Secretary of the Asociación de Ingenerios y Arquitectos de Mexico, lecturer, newspaperman, and author of articles on literary, political, and economic subjects, has also been active for many years in federal service in Mexico and as representative of his country elsewhere. He was born in Hidalgo del Parral, Chihuahua, Mexico, in 1867. Shortly after completing the mining engineering course at the Escuela Nacional de Ingenieros in the City of Mexico, he was appointed assayer and inspector at the Durango branch of the federal mint. Subsequently he was transferred to the post of chief of the federal assay office at Monterey, and in 1898 to that of director of the mint at Culiacan. In 1903 Señor Dominguez was appointed Postmaster-General of the Republic by President Diaz, who, eight years later, transferred him to his cabinet as Minister of the Department of Public Works. President Huerta appointed him to posts of responsibility in his government, including that of Chief of the Department of Commerce. In 1920, Señor Dominguez was elected to the House of Representatives from the District of Parral. Subsequently he served as mining engineer with different interests; as editor of the illustrated review, *Reconstruccion;* and as director of the newspaper, *El Comercio.* He is the author of several books.

Netherlands. PROF. DR. DANIEL DRESDEN. Presented by His Excellency J. H. van Royen, Minister to the United States.

Daniel Dresden, since 1928 president of the Jaffa Engine Works, Utrecht, Netherlands, was born in Amsterdam in 1886 and obtained his early technical training there. Later he attended the Technical Academy at Delft, from which he received a degree in mechanical engineering in 1910. After engaging for a short time in the design and manufacture of safes and locks at the Lips works, and in designing a power station and distributing system in Leeuwarden, Professor Dresden became associated with Stork Brothers, of Hengelo, Netherlands, as chief designing engineer in their steam-turbine and centrifugal-pump departments. In 1920 he was appointed professor of mechanical technology at the Technical Academy of Delft. Since that time he has also served as consulting engineer for municipal power stations and made study trips and steam-turbine tests in Switzerland, France, Scandinavia, Hungary, Czechoslovakia, Spain, and the United States.

Sweden. MR. VILHELM NORDSTRÖM. Presented by His Excellency W. Bostrom, Minister to the United States.

Vilhelm Fredrik André Nordström, technical manager of the De Laval Steam Turbine Company, Stockholm, was born at Gefle, Sweden, in 1883. He was graduated from the Royal Technical University of Stockholm in 1905, and until 1911 was associated with Prof. J. E. Cederblom's Mechanical Laboratory, devoting himself to aerodynamics and steam power. The following year he was graduated from the Commercial Institute of Stockholm and became connected with the De Laval Company. He was appointed to his present position in 1918. Mr. Nordström served as Swedish delegate to the conference of the International Electrotechnical Commission in New York in 1926, and to the meeting of the I.E.C. Advisory Committee No. 5 on Steam Turbines at The Hague in 1928. He contributed a paper on "High Steam Pressures" to the World Power Conference in London in 1924.

Switzerland. PROF. DR. AUREL STODOLA. Represented by His Excellency, Marc Peter, Minister to the United States.

Aurel Stodola, professor of mechanical engineering at the Swiss Federal Technical University, Zurich, from 1892 to 1929, and distinguished engineer and author in the field of heat engines, was born in Liptó-Szent Miklós, Hungary (now part of Czechoslovakia), in 1859. He was graduated from the Swiss Federal Technical University in 1881, and later studied in Berlin and Paris. Prior to his appointment as professor at the University of Zurich he was connected with Staatsmaschinenfabrik, of Budapest, and the Prager Maschinenfabrik, formerly Ruston & Co., of Prague. Dr. Stodola has published numerous scientific papers and treatises on heat engines, and his treatment of this subject in his book entitled "Dampf und Gasturbinen" won him the Grashof Medal of the Verein deutscher Ingenieure. The book has been translated into both English and French.

United States. DR. C. E. GRUNSKY. Presented by the Honorable Joseph P. Cotton, the Acting Secretary of State.

Carl Ewald Grunsky, consulting engineer, San Francisco, authority on municipal utility management, past city engineer of San Francisco and adviser on irrigation and reclamation, was born in 1855 near Stockton, San Joaquin County, California. After graduating from the Stockton high school in 1870 he went to Stuttgart, Germany, for his engineering education, and in 1877 was graduated from the Polytechnic Institute in that city. For the following ten years he worked in the California State Engineer's Department. During this service he had charge of irrigation investigations in the Great Central Valley of California and made special studies of the water resources of the state, giving attention to rainfall and streamflow and to methods of water utilization. The Governor of California appointed him a member of the Examining Board on Rivers and Har-

bors, and later he became consulting engineer on flood-control studies under the State Commissioner of Public Works. Mr. Grunsky established himself as consulting engineer first at Sacramento and then in San Francisco. He was engineer for a number of irrigation districts, notably the Modesto, and on water and sewerage projects for the city of San Francisco. From 1899 to 1903, under its new charter, Mr. Grunsky was city engineer of San Francisco; under his recommendation the development of a water supply from the Tuolumne River and the Hetch Hetchy project was started. In 1904 President Roosevelt appointed him a member of the Panama Canal Commission; the next year, when the Canal Commission was reorganized, Mr. Grunsky was appointed consulting engineer in the U. S. Reclamation Service and adviser to the Secretary of the Interior on reclamation problems. He resigned in 1907 to take up private practice.

Uruguay, S. A. PROF. DONATO GAMINARA. Represented by His Excellency J. Varela, Minister to the United States.

Donato Gaminara, civil engineer, was born in Montevideo, Uruguay, in 1886, and was graduated in civil engineering in 1906 from the university in that city. He became a professor in the university, and later was dean of its engineering faculty and professor of ports and lighthouses. He was engaged in engineering work for three years in Rio Grande do Sul, in New York for one year, and is now engaged in consulting engineering work in Uruguay. Señor Gaminara is a past-president of the Society of Civil Engineers of Uruguay and of the Society of Engineers of Montevideo, and a past governor of the Rotary International for the district covering Argentina, Brazil, and Uruguay. He was a member of the Pan-American Highway Commission to the United States in 1924.

THE DANIEL GUGGENHEIM MEDAL

First Award

Medalist for 1929, ORVILLE WRIGHT. Medal presented by Wm. F. Durand, President, Guggenheim Medal Board.

"To Orville Wright, for design and construction, with his brother, now deceased, of the first successful engine-propelled airplane." With such simplicity of citation the Board of Award bestowed the first Daniel Guggenheim Medal. But the achievement itself is one which had baffled scientists, technicians, practical men, and dreamers ever since the first inquiring mind watched a bird in flight.

Orville Wright was born in Dayton, Ohio, in 1871, and educated in the public schools. He and his brother Wilbur experimented with models of airplanes practically all their lives. They saw the problem of successful flight as two-fold: First, they figured they must produce some form of glider which would stay in the air long enough to give them actual experience in the air; and then they needed an engine light enough but powerful enough to supply adequate motive power. The story of their experiments with gliders, and of their development of an engine which would successfully raise and keep a plane aloft, is a familiar one. Their first successful flight with a heavier-than-air machine was made on December 17, 1903. They are the inventors, too, of the system of controls used in practically all flying machines today.

THE GANTT GOLD MEDAL

Medalist for 1930, FRED J. MILLER. Presented for the award by Dexter S. Kimball, Past-President of the A.S.M.E. Medal presented by L. P. Alford, Chairman, Gantt Medal Board.

When Fred J. Miller was factory manager for the Remington typewriter factories, he engaged Mr. Gantt as his consultant on management problems, and a friendship began between the two men which terminated only with Mr. Gantt's death. In recognition of the fact that Mr. Miller, in the Remington factories, made one of the first applications on a large scale of sound principles of scientific management, the Gantt Gold Medal for 1930 has been awarded to him.

Fred J. Miller was born at Yellow Springs, Ohio, in 1857. After a high-school education he entered industry to serve a four-year apprenticeship as a machinist. He became interested in shop-management problems early in life, and while acting as foreman of Warder, Bushnell, Glessner and Company he published accounts of the methods he was using there which attracted the attention of the *American Machinist*. The result was that he was called by the *American Machinist* to an editorial position, from which he rose to be editor-in-chief. After twenty years in journalism, Mr. Miller was for nine years general manager of the group of Remington typewriter factories. During the war he was commissioned Major of Ordnance in the United States Army, where he was engaged in organization and personnel work. He was president of the A.S.M.E. in 1920.

A.S.M.E. MEDAL

Medalist for 1929, WILLIAM LEROY EMMET. Presented for the award by Arthur M. Greene, Jr., Chairman, Committee on Awards of the Society. Medal presented by Conrad N. Lauer, Vice-President of the Society.

The award of the A.S.M.E. Medal for 1929 was made to Mr. William LeRoy Emmet for his "contributions in the development of the steam turbine, electric propulsion of ships, and other power-generating apparatus." He directed the development of the Curtis turbine by the General Electric Company, every detail of which was radically new; designed the machinery for the first ship driven by electric motors; was the first serious promoter of electric ship propulsion; and developed the mercury-vapor power process.

Mr. Emmet was born in 1859 at Pelham, N. Y., and was graduated from the U. S. Naval Academy. He left the Navy, however, to take up electrical engineering. His most important electrical work has been in the development of the general use of alternating currents and in the invention and design of machinery to further their practical application. In the mechanical-engineering field, his work in the development and introduction of the steam turbine has been outstanding. He is the inventor of the vertical-shaft steam turbine, of which a large number have been built, and many details of turbine design now in general use are to his credit. He is best known recently for the development on a commercial scale of the mercury-vapor process for the generation of power.

MELVILLE MEDAL

Medalist for 1929, JOSEPH WICKHAM ROE. Presented for the Award by Arthur M. Greene, Jr., Chairman, Committee on Awards of the Society. Medal presented by Conrad N. Lauer, Vice-President of the Society.

Professor Roe's paper, "Principles of Jig and Fixture Practice," presented at the Annual Meeting of The American Society of Mechanical Engineers in December, 1928, won for him the award of the Melville Medal for 1929. The Committee's decision to award the medal for this paper as "a thesis of exceptional merit" is based upon the fact that it presents for the first time in condensed form a résumé of the principles of design of jigs and fixtures, and adapts the formulas derived by the Society's Materials Handling Division to the economic problems involved in determining the investment justified in jigs and fixtures.

Joseph W. Roe was born in New York in 1871 and was graduated from Sheffield Scientific School in 1895. He became interested in machine tools, their problems in design and manufacture, early in life, and had years of practical experience with these problems, with various firms, before entering the profession of teaching. His book, "English and American Tool Builders," is an important historical contribution on the machine-tool industry. Professor Roe's interests, apart from engineering education, still lie in the machine-tool field and in the practical problems of industrial management. He has served as president of the Society of Industrial Engineers. In 1925 he directed a study of civil aviation for the Department of Commerce and the American Engineering Council. (He had been a major in the Air Service of the United States Army during the World War.) He accepted his present position as professor of industrial engineering and head of the department of industrial engineering at New York University in 1920, following more than a decade as a member of the engineering faculty at Yale.

THE ANNIVERSARY DINNER

The Fiftieth Anniversary Dinner was held at the Mayflower Hotel on Tuesday night. At seven o'clock, their excellencies, the ambassadors of the several countries whose engineers had been honored at the convocation for the conferring of awards, their wives, and guests having assembled with the members of the Society and their guests to the number of more than eight hundred, four flourishes of the trumpet announced the arrival of the President of the United States and his party, and as the Marine Band played "Hail to the Chief," the President crossed the room and took his place amid enthusiastic applause.

Following the dinner the toastmaster, Dr. William F. Durand, past-president of the Society, expressed the great regret which every one felt at the unavoidable absence of Charles Piez, president of the Society, and called upon Secretary Calvin W. Rice to read the greeting which Mr. Piez had written.

Dr. Robert A. Millikan, director of the Norman Bridge Labo-

ratory of Physics of the California Institute of Technology, Pasadena, Calif., Nobel prize winner in physics in 1923, A.S.M.E. medalist in 1926, Edison medalist of the A.I.E.E., Hughes medalist of the Royal Society of Great Britain, research physicist, author, interpreter of science to the layman, was the principal speaker. His address dealt with the bond between pure physics and engineering, and was divided into four parts, having to do with (1) the direction and shape of the curve of history itself, (2) the method that seems to have been used in drawing that upward curve, (3) the identification of its draftsmen, and (4) what seem to be our own opportunities and responsibilities as scientists and engineers in connection with it. The address was summarized in *Mechanical Engineering*, May, 1930, page 525.

The Hoover Gold Medal Award

The first award of the Hoover Gold Medal, commemorating the civic and humanitarian achievements of Herbert Hoover, was presented to the man for whom it was named.

The trust fund creating the award was the gift of Conrad N. Lauer, of Philadelphia. It is held by The American Society of Mechanical Engineers and is administered by a Board of Award consisting of representatives of the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, and the American Institute of Electrical Engineers. The medal is to be awarded by engineers to a fellow-engineer for distinguished public service.

J. V. W. Reynders, past-president of the American Institute of Mining and Metallurgical Engineers, delivered the address presenting the medalist, and following Mr. Reynders' address, Dean Dexter S. Kimball, president of the Board of Award and past-president of the A.S.M.E., presented the medal to the Honorable Herbert Hoover. His response was included in the report of the celebration in the May, 1930, issue of *Mechanical Engineering*.

Wednesday in Washington

Wednesday in Washington was devoted to excursions, sightseeing, and the reception at the White House. The first excursion of the morning was to the Navy Yard to see the naval gun factory, the experimental model basin, the wind tunnel, and the diving school. Sightseeing tours of Washington, Arlington, Georgetown, Fort Meyer, and Mount Vernon were arranged for those who did not visit the Navy Yard. In the afternoon the Bureau of Standards, where special arrangements had been made to inspect the laboratories where work was in progress, and other important government buildings were visited. At the White House Reception, President and Mrs. Hoover shook hands with more than one thousand guests.

Institutions Officially Represented at the Fiftieth Anniversary Celebration

Agricultural and Mechanical College of Texas
L. W. Wallace, Edgar C. Rack

Albany Society of Engineers
Ernest McN. Scarle

American Academy of Arts and Sciences
Lionel S. Marks, Edward Furber Miller

American Association for the Advancement of Science
Robert A. Millikan, Charles Russ Richards

American Association of Engineers
Harold Almert, D. B. Steinman

American Association of Petroleum Geologists
Arthur Knapp

American Association of State Highway Officials
Jacob L. Bauer, H. D. Williar

American Association of University Professors
George B. Pegram, William T. Magruder

American Astronomical Society
Raymond S. Dugan

American Automobile Association
George C. Diehl

American Boiler Manufacturers Association
George S. Barnum, E. R. Fish

American Bureau of Welding
C. A. McCune, H. L. Whittemore

American Ceramic Society
Ross C. Purdy

American Chemical Society
Elmer A. Sperry, W. M. Corse

American Concrete Institute
Maxwell M. Upson, P. H. Bates

American Economic Association
Horace B. Drury, Harlow S. Person

American Electric Railway Association
A. T. Clark, R. H. Dalgleish

American Electrochemical Society
Elmer A. Sperry

American Engineering Council
Carl E. Grunsky, A. W. Berresford

American Forestry Association
George H. Collingwood

American Foundrymen's Association
Guilliam H. Clamer, Fred Erb

American Gear Manufacturers Association
George L. Markland

American Gas Association
Conrad N. Lauer, John A. Clark, Jr.

American Geographical Society
Hamilton Fish Kean, Frederic C. Walcott

American Institute of Architects
Frederick L. Ackerman, William I. Deming, William L. Plack, Stephen F. Voorhees

American Institute of Chemical Engineers
H. C. Parmelee, Alfred H. White

American Institute of Consulting Engineers
Philip W. Henry, Frederic A. Molitor

American Institute of Electrical Engineers
Harold B. Smith, A. W. Berresford

American Institute of Mining and Metallurgical Engineers
W. H. Bassett, George D. Barron

American Institute of Refrigeration
Louis Baron, Wrisley Brown

American Institute of Steel Construction, Inc.
L. H. Miller

American Institute of Weights and Measures
C. R. Burt, Walter M. McFarland

American Library Association
George F. Bowerman, Albert F. Zahm

American Management Association
C. S. Ching, Thomas R. Jones

American Mathematical Society
George A. Campbell, E. V. Huntington

American Physical Society
George K. Burgess, Harvey N. Davis, Arthur L. Day, H. E. Ives

American Railway Association (Mechanical Division)
J. E. Ennis, G. W. Rink

American Railway Engineering Association
C. C. Cook, John R. Leighty

American Society for Municipal Improvements
Edward S. Rankin

American Society for Steel Treating
Francis F. Lucas, John A. Mathews

American Society for Testing Materials
T. D. Lynch, A. A. Stevenson

American Society of Agricultural Engineers
S. H. McCrory, R. W. Trullinger

American Society of Civil Engineers
WILLIAM BARCLAY PARSONS, FRANCIS LEE STUART

American Society of Heating and Ventilating Engineers
W. H. CARRIER, L. A. HARDING

American Society of Naval Engineers
R. W. PAINE, O. L. COX

American Society of Refrigerating Engineers
H. D. EDWARDS, DAVID L. FISKE

American Society of Swedish Engineers
ERIC A. LOF, ROBERT WERNER

American Standards Association
WILLIAM J. SERRILL, A. A. STEVENSON

American Welding Society
J. H. DEPPELER, J. C. LINCOLN

Army Ordnance Association
L. A. CODD, C. G. METTLER

Asociacion de Ingenieros y Arquitectos de Mexico
GUILLERMO B. PUGA, NORBERTO DOMINGUEZ

Association des Ingénieurs Conseils de la République Tchécoslovaque
J. NOVAK

Association of Czechoslovakian Engineers and Architects in Praha
JOSEF Z. SCHNEIDER

Association of Edison Illuminating Companies
W. L. ABBOTT

Association Technique Maritime et Aéronautique (France)
MASON SMITH CHACE, WILLIAM F. DURAND

Bergakademie Clausthal (Germany)
HERMANN MAIER-LEIBNITZ

Bergakademie Freiberg (Germany)
FREDERICK GLEASON CORNING, OTTO FRITZSCHE, HERMANN MAIER-LEIBNITZ

British Association for the Advancement of Science
P. J. COWAN

British Engineering Standards Association
WILLIAM HENRY PATCHELL, LOUGHNAN ST. L. PENDRED

Brooklyn Engineers Club
W. W. MACON

Brown University
JAMES ALEXANDER HALL, WILLIAM H. KENERSON

California Institute of Technology
R. L. DAUGHERTY, ROBERT A. MILLIKAN

Carnegie Institute of Technology
THOMAS S. BAKER, SUMNER B. ELY

Carnegie Institution of Washington
ARTHUR L. DAY, J. A. FLEMING

Case School of Applied Science
PAUL J. KIEFER

Catholic University of America
THOMAS J. MACKAVANAGH, GEORGE A. WESCHLER

Chalmers Tekniska Institut (Sweden)
ERIC A. LOF., ROBERT WERNER

Chemical Society (England)
MARCUS BENJAMIN, H. D. DAKIN

Chicago Technical College
CHARLES W. MOREY

Clarkson Memorial College of Technology
JOHN ALEXANDER ROSS, JR., JOSEPH EUGENE ROWE

Clemson Agricultural College
S. B. EARLE, B. E. FERNOW

Cleveland Engineering Society
WARNER SEELY

College of the City of New York
ARTHUR BRUCKNER, FREDERICK KUHLEN

Columbia University
CHARLES EDWARD LUCKE, WILLIAM A. SHOUDY

Cooper Union
GEORGE F. BATEMAN, F. M. HARTMANN

Cornell University
DEXTER S. KIMBALL

Dansk Ingeniörforening (Denmark)
HAROLD I. FEIIS, A. C. GRONBECK

Dartmouth College
HAROLD JOHN LOCKWOOD

Den Norske Ingeniörforening (Norway)
BJARNE JOHNSEN, C. B. THORNE

Den Polytekniske Forening
HELGE SCHIBSTED

Detroit Engineering Society
C. F. HIRSHFELD

Drexel Institute
J. H. BILLINGS

East London College
ERNEST WIGNALL

Electric Hoist Manufacturers Association
F. A. HATCH, H. W. STANDART

Engineering Foundation, Inc.
H. P. CHARLESWORTH, FRANCIS LEE STUART

Engineering Institute of Canada
ALEX. J. GRANT, CHARLES H. MITCHELL

Engineering Societies of Boston
CHARLES H. CHASE, PERCY C. IDELL

Engineering Societies Research Board of Engineering Foundation, Inc.
GEORGE L. KNIGHT, GEO. A. ORROK

Engineers and Architects Club of Louisville
B. M. BRIGMAN, GEORGE W. HUBLEY

Engineers Club of Baltimore
JOHN R. BAKER, WILLIAM M. PASSANO

Engineers Club of Philadelphia
FRANCIS P. WITMER, D. ROBERT YARNALL

Engineers' Society of Milwaukee
HANS DAHLSTRAND, ARTHUR SIMON

Engineers' Society of Northeastern Pennsylvania
FREDERICK L. MOORE

Engineers' Society of Western Pennsylvania
CHARLES W. BENNETT

Fédération des Associations Belges d'Ingénieurs (Belgium)
GASTON DE BETHUNE, ALBERT DE SMAELE

Florida Engineering Society
C. E. GORTON

Franklin Institute of the State of Pennsylvania
NATHAN HAYWARD, HOWARD MCCLENAHAN

Georg August Universität (Germany)
J. J. WILH. SEEDORF

George Washington University
B. C. CRUICKSHANKS, A. F. JOHNSON

Heating and Piping Contractors National Association
J. E. RUTZLER, ROBERT D. WILLIAMS

Illuminating Engineering Society
S. G. HIBBEN, J. FRANKLIN MEYER

Imperial College of Science and Technology (England)
W. A. DEL MAR, WILLIAM L. WATERS

Institute of Fuel (England)
CARL J. JEFFERSON, WILLIAM HENRY PATCHELL

Institute of Marine Engineers
ROBERT MCGREGOR, J. S. MILNE

Institute of Metals (England)
W. M. CORSE, W. H. BASSETT

Institute of Radio Engineers
THOMAS MCL. DAVIS, C. B. JOLLIFFE

Institution of Automobile Engineers (London)
A. C. BURGOINE, ALFRED F. MASURY

Institution of Civil Engineers (England)
WILLIAM HENRY PATCHELL, JOHN BONSALL PORTER

Institution of Electrical Engineers (London)
GANO DUNN, WILLIAM HENRY PATCHELL

Institution of Engineering Inspection (England)
HAL GUTTERIDGE
Institution of Engineers and Shipbuilders in Scotland
J. R. JACK, H. C. SADLER
Institution of Mechanical Engineers (London)
WILLIAM HENRY PATCHELL, LOUGHNAN ST. L. PENDRED
Institution of Mining Engineers (London)
GEOFFREY MERTON GULLICK
Institution of Naval Architects (London)
JAMES FRENCH, H. C. SADLER
Institution of Structural Engineers
E. MCCULLOUGH
International Electrotechnical Commission
CLAYTON H. SHARP
International Railway Fuel Association
J. E. DAVENPORT
Interstate Commerce Commission, Bureau of Safety
JOHN P. KELLY
Iowa Engineering Society
H. F. CLEMMER
Iowa State College of Agriculture and Mechanic Arts
W. H. MEEKER
Iron and Steel Institute (England)
CHARLES M. SCHWAB

Johns Hopkins University
A. G. CHRISTIE
Joseph A. Holmes Safety Association
D. HARRINGTON
Junior Institution of Engineers (England)
A. A. CARMAN, E. D. ROBERTS

Kansas State Agricultural College
J. P. CALDERWOOD
Kogakkai (Japan)
MASAWO KAMO, A. OUCHI
Koninklijk Instituut van Ingenieurs (Holland)
D. DRESDEN, A. PLATE

Lafayette College
DONALD BISHOP PRENTICE
Lehigh University
F. V. LARKIN, CHARLES RUSS RICHARDS
Louisiana Engineering Society
PETER J. DROMGOOL
Louisiana State University and Agricultural and Mechanical College
HAMILTON JOHNSON

Masarykova Akademie Práce (Czechoslovakia)
JOSEF Z. SCHNEIDER
Massachusetts Institute of Technology
EDWARD FURBER MILLER, S. W. STRATTON
McGill University
F. T. H. BACON, C. M. MCKERGOW
Mellon Institute of Industrial Research
H. S. COLEMAN, R. H. HEILMAN
Michigan Engineering Society
F. N. MENEFEE
Michigan State College
H. B. DIRKS
Michigan State College of Agriculture and Applied Science
J. R. MCCOLL
Mining and Metallurgical Society of America
J. V. N. DORR, F. W. O'NEIL
Ministry of Public Works (Rome, Italy)
LUIGI LUIGGI

National Advisory Committee for Aeronautics
STARR TRUSCOTT
National Aeronautic Association of U. S. A.
CHARLES L. LAWRENCE
National Association of Power Engineers, Inc.
FREDERICK FELDERMAN, WILLIAM J. REYNOLDS
National Board of Fire Underwriters
GEORGE W. BOOTH
National Coal Association
EDWARD PAGE
National District Heating Association
WILLIAM J. BALDWIN, GEORGE W. MARTIN
National Electrical Manufacturers Association
A. W. BERRESFORD, HENRY G. REIST
National Electric Light Association
H. P. LIVERSIDGE
National Industrial Conference Board, Inc.
MAGNUS W. ALEXANDER, W. C. DICKERMAN
National Institute of Social Sciences
GUSTAVE R. TUSKA
National Machine Tool Builders' Association
E. J. KEARNEY, LUTHER D. BURLINGAME
National Research Council
MAURICE HOLLAND, ELMER A. SPERRY
National Safety Council
C. B. AUEL
Newcomen Society (England)
CHARLES PENROSE, LOUGHNAN ST. L. PENDRED
New England Water Works Association
JOHN R. FREEMAN, CHARLES T. MAIN
Newark College of Engineering
J. ANSEL BROOKS, ALLAN R. CULLIMORE
New York Academy of Sciences
GEORGE F. KUNZ, GEORGE B. PEGRAM, GEORGE O. SQUIER, D. W. TAYLOR
New York University
COLLINS P. BLISS, WILLIAM R. BRYANS
North Carolina State College of Agriculture and Engineering
WILLIAM J. DANA, LILLIAN L. VAUGHAN
North East Coast Institution of Engineers and Shipbuilders (England)
E. W. FRASER-SMITH
North of England Institute of Mining and Mechanical Engineers
CLARENCE R. CLAGHORN

Oesterreichischer Ingenieur und Architekten Verein (Austria)
GUSTAV LINDENTHAL, ADOLF GIESL-GIESLINGEN
Ohio Mechanics Institute
EDWARD A. MULLER
Ohio State University
JAMES E. BOYD, WILLIAM T. MAGRUDER
Optical Society of America
H. E. IVES, CARL W. KEUFFEL

Pennsylvania State College
R. L. SACKETT, A. J. WOOD
Polytechnic Institute (Brooklyn)
EDWIN F. CHURCH, JR.
Portland Cement Association
GEORGE A. RICKER, RAYMOND R. BEAR
Power Transmission Association
W. S. HAYS, F. H. WILLARD
Pratt Institute (Brooklyn)
SAMUEL S. EDMANDS, CHARLES PRATT
Princeton University
FRANK L. EIDMANN, ARTHUR M. GREENE, JR.
Providence Engineering Society
LUTHER D. BURLINGAME, WILLIAM H. KENERSON
Purdue University
W. L. BATT, W. H. WINTERROWD

Refrigerating Machinery Association
FRED NOLDE
Regia Scuola d'Ingegneria di Torino, di Roma, and Navale (Italy)
LUIGI LUIGGI
Rensselaer Polytechnic Institute
EDWIN A. FESSENDEN, GRANT K. PALSGROVE

Rhode Island State College
WILLIAM ANDERSON, R. L. WALES

Rice Institute
JOSEPH H. POUND

Robert College (Turkey)
L. A. SCIPIO

Rochester Engineering Society
O. L. ANGEVINE, GEORGE C. VAN VECHTEN

Royal Technical College (Copenhagen)
J. L. HOLST, O. E. MOGENSEN

Royal Technical College (Scotland)
A. L. MELLANBY

Rutgers University
PARKER H. DAGGETT, ROBERT C. H. HECK

Sindacato Nazionale Fascista degli Ingegneri (Italy)
LUIGI LUIGGI

Smithsonian Institution
CHARLES G. ABBOTT, CARL W. MITMAN

Sociedad Colombiana de Ingenieros (South America)
JORGE ALVAREZ LLERAS

Sociedad Cubana de Ingenieros (Cuba)
JOSÉ M. BABÉ, ALEXANDER POTTER

Société Belge des Ingénieurs et des Industriels
GASTON DE BETHUNE

Société des Ingénieurs Civils de France
GEORGES CLAUDE, CHARLES DE FRÉMINVILLE

Société Française des Électriciens (France)
A. E. KENNELLY, C. O. MAILLOUX, CLAYTON H. SHARP

Society for Electrical Development
A. W. BERRESFORD, H. P. LIVERSIDGE

Society for the Promotion of Engineering Education
R. I. REES, W. S. RODMAN

Society of American Military Engineers
GEO. A. ORROK, BLAKE R. VAN LEER

Society of Engineers (England)
R. W. A. BREWER

Society of Engineers of Eastern New York
GRANT K. PALSGROVE

Society of Industrial Engineers
JOHN M. CARMODY, GEORGE C. DENT

Society of Naval Architects and Marine Engineers
WALTER M. MCFARLAND, GEORGE H. ROCK

Society of Terminal Engineers
CHARLES W. BRYAN, CHARLES H. NEWMAN

South African Institution of Engineers
W. E. JOHN, R. C. WARRINER

Spolek Ceskoslovenskych Inzenyru (Czechoslovakia)
G. J. HAUSER

Stanford University
THEODORE JESSE HOOVER, WILLIAM F. DURAND

State University of Iowa
WILLIAM J. BRUSH, J. LEO SCANLON

Stevens Institute of Technology
GEORGE GIBBS, D. S. JACOBUS, WALTER KIDDE

Svenska Teknologforeningen (Sweden)
VILHELM NORDSTRÖM

Swarthmore College
CHARLES G. THATCHER

Syracuse University
H. W. AUSTIN, GEORGE F. KERN

Taylor Society
MORRIS L. COOKE, EDWARD EYRE HUNT

Technische Hochschule in Wien (Austria)
R. E. HELLMER

Technischen Hochschulen of Aachen, Berlin, Braunschweig, Breslau, Darmstadt, Dresden, Hannover, Karlsruhe, Munchen, Stuttgart, and Danzig (Germany)
HERMANN MAIER-LEIBNITZ

Tufts College
CHARLES H. CHASE

Tulane University of Louisiana
WILLIAM B. GREGORY, HUGH M. KRUMBHAAR

Union College
MORTIMER F. SAYRE

Université de Paris a la Sorbonne (France)
M. BRAUNSCHVIG, MAISON FRANÇAISE MEILLET

University (Glasgow, Scotland)
H. C. SADLER

University (Leeds, England)
PERCY NICHOLLS

University (Manchester, England)
ALBERT KINGSBURY

University College (England)
P. J. COWAN, WILLIAM HENRY PATCHELL

University of Adelaide (Australia)
A. H. CHAPMAN, R. W. TASSIE

University of Birmingham (England)
LIONEL S. MARKS

University of California
CHARLES DERLETH, B. F. RABER, AMBROSE SWASEY

University of Cambridge (England)
CHARLES A. PARSONS

University of Delaware
ROBERT L. SPENCER

University of Edinburgh
ROBERT W. ANGUS

University of Illinois
MORGAN BROOKS

University of Kentucky
F. PAUL ANDERSON

University of London (England)
P. J. COWAN, WILLIAM HENRY PATCHELL

University of Louisville
B. M. BRIGMAN

University of Maine
R. H. FERNALD

University of Maryland
A. N. JOHNSON, J. N. C. NESBIT

University of Michigan
H. C. SADLER

University of Minnesota
JOHN R. DU PRIEST

University of Missouri
EDWIN A. FESSENDEN

University of New Hampshire
E. L. GETCHELL

University of Oklahoma
J. H. FELGAR

University of Oxford (England)
MILAN W. GARRETT

University of Pennsylvania
R. H. FERNALD, WILLIAM H. KAVANAUGH

University of Pittsburgh
JOHN A. DENT, E. A. HOLBROOK

University of Rochester
JOSEPH W. GAVETT

University of St. Andrews (Scotland)
JOHN JOHNSTON

University of Toronto
ROBERT W. ANGUS, CHARLES H. MITCHELL

University of Virginia
WILLIAM M. THORNTON

University of Wisconsin
BEN G. ELLIOTT

U. S. Army Chemical Warfare Service
CHARLES W. EXTON, JAMES H. BOGART

U. S. Army Infantry
JAMES E. ALLISON, STEPHEN G. HENRY

U. S. Army Ordnance Department
PHILIP R. FAYMONVILLE, C. G. METTLER

U. S. Army Quartermaster's Department
E. C. GERE, F. S. SIMPSON

U. S. Bureau of Mines
O. P. Hood

U. S. Bureau of Standards
Lyman J. Briggs, Hobart C. Dickinson

U. S. Coast and Geodetic Survey
Harold A. Cotton, Douglass L. Parkhurst

U. S. Department of Agriculture, Bureau of Chemistry and Soils
F. G. Cottrell, C. H. Kunsman

U. S. Department of the Interior, Geological Survey
W. C. Mendenhall, George Otis Smith

U. S. Military Academy
Glen E. Edgerton, A. G. Gillespie

U. S. National Committee of International Electrotechnical Commission
A. E. Kennelly, C. O. Mailloux

U. S. Navy Department, Bureau of Construction and Repair
George H. Rock

U. S. Navy Department, Bureau of Engineering
O. L. Cox, R. W. Paine

U. S. Post Office Department
Frank E. McMillin

U. S. Shipping Board
J. E. Bailey, William T. Hayes

U. S. War Department, Office of the Chief of Engineers
William J. Barden, Herbert Deakyne

Vanderbilt University
Lytle Brown, Olin H. Landreth

Verein deutscher Ingenieure
Conrad Matschoss, Karl Maybach

Verein Schweizerischer Maschinen-Industrieller (Switzerland)
Henry A. Naville

Vermont Society of Engineers
R. K. Blanchard, Guy Hubbard

Villanova College
Charles A. Beckermann

Virginia Polytechnic Institute
J. S. A. Johnson, E. B. Norris

Washington Society of Engineers
E. W. Ely, William S. Conant

Washington University
E. R. Fish

Western Society of Engineers
William S. Monroe, Edgar S. Nethercut

West Virginia University
C. R. Jones

Worcester Polytechnic Institute
Charles M. Allen, Ralph Earle

Yale University
Samuel W. Dudley, Herbert L. Seward.

Semi-Annual Meeting, Detroit, Mich.

MORE than 600 members of the Society and their guests attended the Semi-Annual Meeting at Detroit, Mich., from June 9 to 12, 1930. Technical sessions and business and committee meetings were held at the Book-Cadillac Hotel.

Because of his continued illness, President Piez was unable to be present to preside at the meeting of the Council, held on Monday morning. Representing him was Colonel Paul Doty, Vice-President of the Society. Past-President Dow was on hand to welcome the Council to Detroit.

A meeting of the standing committee on Local Sections was held Sunday preceding the opening of the meeting; a conference of Local Sections' delegates took place Tuesday morning; and a luncheon of Council with the Local Sections' delegates Tuesday noon. The delegates of the Student Branches held a conference on Wednesday morning. Technical and executive committees were in session throughout the week. Two committee organization meetings were held, those of the technical committees on Splines and Splined Shafts and on Milling Machine Tables, both of which have been created to deal with sections of the work on the standardization of small tools and machine tool elements.

As a result of daily meetings of the Nominating Committee the following nominees for the offices of the Society for 1931 were presented:

President, Roy V. Wright
Vice-Presidents, William A. Hanley, Thomas R. Weymouth, Harvey N. Davis
Managers, W. L. Batt, H. L. Doolittle, H. L. Whittemore
American Engineering Council Delegates, W. R. Webster, Roy V. Wright, Joseph W. Roe, D. Robert Yarnall, E. N. Trump, B. E. Hull, E. O. Eastwood, W. Trinks, Warner Seely, William S. Conant.

For the purpose of receiving discussion of its test code for complete steam-electric power plants, a public hearing of the Power Test Codes Committee was held on Monday morning. Much valuable discussion was presented for consideration in the final revision of the code.

The technical sessions of Monday afternoon were preceded by a business meeting at which Colonel Doty presided. Calvin W. Rice, Secretary, presented for its first reading an amendment to the Constitution of the Society increasing initiation fees for Members and Associates from $25 to $35, establishing a fee of $10 for promotion from Associate Member to Member, and changing the fifteen-dollar fee for the promotion of a Junior to a higher grade to a fee of $15 for his promotion to Associate Member and $25 for promotion to Member. It was voted to submit the amendment to the membership for letter ballot.

Entertainment

The program of entertainment opened with an informal reception and dance on Monday evening. C. F. Hirshfeld, manager of the Society, gave an address of welcome to which a response was made by Colonel Doty.

On Tuesday night the men were entertained at a smoker. Vaudeville players from the Detroit theaters offered a variety of song and dance numbers.

A high point in entertainment was the boat ride on Wednesday, in which approximately 300 members and guests participated. The steamer *Eastern States*, which had been chartered for afternoon and evening, took the party up the Detroit River, past Belle Isle, through Lake St. Clair into the St. Clair River, as far as the Marysville plant of the Detroit Edison Company. The weather was delightful and the ride scenically interesting.

A quartette sang frequently through the afternoon and evening and the program included dancing, deck games, and cards, as well as an excellent dinner.

Inspection Trips

Detroit, with its many automobile manufacturing plants and other interesting industries, provided an ideal location for inspection trips. The general program had been laid out with this in mind, there being no conflicts between technical sessions and inspection trips. On Tuesday afternoon six simultaneous trips were scheduled. Some went to the River Rouge Plant

of the Ford Motor Company, where they saw the assembly line, the glass plant, and machine shop. From there they went to the Ford Airport and the airplane factory, where all-metal tri-motor airplanes were under construction, and where Byrd's plane, the *Josephine Ford*, and Schlee and Brock's *Pride of Detroit* were on exhibition. At Greenfield the party saw the Ford industrial museum, built as a reproduction of Independence Hall at Philadelphia, and the buildings of the Edison Institute of Technology which Ford had recently founded. It was also possible to get a general view of the early American village which is part of the same development, and of the original Menlo Park buildings in which Mr. Edison worked.

Another group chose to inspect the General Motors Research Laboratories, which act in a consulting capacity to all of the General Motors Divisions and which are equipped for a great variety of work. This group also visited the Bohn Aluminum & Brass Co. and the McCord Radiator Corporation.

The third group inspected the General Motors Proving Ground of more than 1000 acres, and the fourth visited the Chevrolet forge plant and the Murray body plant.

The Packard Motor Car Company and the Detroit-Michigan Stove Company were the objectives of the fifth group, while the sixth visited the Cadillac Motor Car Company and the Delray Station of the Detroit Edison Company.

On Thursday afternoon many of the members and their guests visited the Grosse Isle Airport. A buffet luncheon at the Chateau Voyageurs and a demonstration of Eastman air yachts and amphibions preceded an inspection of the airport, where many types of airplanes were to be seen and free demonstration flights were offered to any one who cared to go into the air. An interesting feature was the talk on gliders and the demonstration of the launching of gliders. After the inspection of the Curtiss Flying School, an opportunity was afforded of attending the commencement exercises of the school.

In addition to the trip to Grosse Isle, the program for Thursday included excursions to the Fisher Body plant, Pontiac, Mich.; to the Detroit Seamless Steel Tubes Company, American Brass Company, and Ambassador Bridge; and a general sightseeing trip including an inspection of Greenfield Village. Many special trips were individually arranged, and every courtesy was extended those who wished to stay over until Friday to visit such plants as the Yellow Coach and Truck Plant, the Oakland and Pontiac plants at Pontiac, Mich., and the dry-quenching coke plant of the Consumers' Power Company, at Flint, Mich.

Ladies' Program

In order to provide for the ladies who attended the meeting and who did not join in the excursions of Tuesday afternoon, special arrangements were made. An automobile trip that afforded an opportunity to see something of Detroit and its suburbs ended at the Detroit Golf Club, where tea was served. That evening, while the men were at the smoker, the ladies held a bridge tournament in the Crystal Ball Room. On Wednesday they joined the boat trip, and on Thursday some went to Grosse Isle, while others visited Greenfield Village.

Technical Program

The following summary of the technical program gives the various sessions, the papers presented, and their authors.

Monday Morning, June 9

Machine Shop Practice (I)

(Auspices of Machine Shop Practice Division)

Refinements in Finishing Cylindrical Bores, J. W. Hindes and James G. Young
What Happens When Metal Is Cut, O. W. Boston

Properties of Metals

(Auspices of Joint Research Committee on Effect of Temperature on Properties of Metals)

Flow Characteristics of Special Fe-Ni-Cr Alloys and Some Steels at Elevated Temperatures, H. J. French, Wm. Kahlbaum, and A. A. Peterson
Flow Characteristics of Some Lead Cable Sheath at Temperatures above Atmospheric, C. L. Clark and C. Upthegrove
An Apparatus for the Determination of Creep at Elevated Temperatures, A. E. White

Applied Mechanics (I)

(Auspices of Applied Mechanics Division)

Power Application to Oscillating Axles, Alain Madlé
Automatic Brakes with Servo-Action, F. Loewenberg

Monday Afternoon, June 9

Machine Shop Practice (II)

SYMPOSIUM ON TUNGSTEN CARBIDE

(Auspices of Machine Shop Practice Division)

Introductory Address, Ernest F. DuBrul
Cutting Tests with Cemented Tungsten-Carbide Lathe Tools, T. G. Digges
Application of Tungsten Carbide to Saws, C. M. Thompson
The Use of Tungsten Carbide as a Cutting Material on Heavy Machine Tools, Coleman Sellers, 3d
Report of Metal Cutting Committee on Tungsten Carbide (A.S.M.E. Research Sub-Committee), Frank C. Spencer

Boiler Feedwater Studies

(Auspices of Joint Research Committee on Boiler Feedwater Studies)

Electrical-Conductance Measurements of Water and Steam, and Applications in Steam Plants, Max Hecht and D. S. McKinney
Fractures in Boiler Metal, A. E. White

Applied Mechanics (II)

(Auspices of Applied Mechanics Division)

Steady Forced Vibration as Influenced by Damping, Lydik S. Jacobsen
Longitudinal Wave Transmission and Impact, L. H. Donnell

Tuesday Morning, June 10

Industrial Power

(Auspices of Power Division)

Tests of the Resistance to Repeated Pressure of Forged, Riveted, and Welded Boiler Shells, H. F. Moore
Boiler Settings for Burning Refuse Wood, Charles S. Gladden

Paper and Pulp Conference

(Auspices of Printing Industries Division)

Welcome to Detroit, John E. Coulter
Welcome from the Printing Industry, George R. Keller
Technical Specifications for Paper Users, B. L. Wemhoff
Permanence Standards for Printing and Writing Papers, B. W. Scribner

Wood Industries

(Auspices of Wood Industries Division)

Airplane Spruce, E. J. Fishbaugh
End-Matching, Edge-Jointed and Surface-Laminated Wood Parts for Auto-Body Building, Gilbert G. White
Training Men for the Wood-Using Industries, Samuel T. Dana

Applied Mechanics (III)

(Auspices of Applied Mechanics Division)

The Stresses in Rotating Disks, Thomas H. Frost and K. F. Whitcomb
Flow of Gases at a Rate Exceeding the Acoustic Velocity, O. G. Tietjens

Wednesday Morning, June 11

FUELS AND POWER

(Auspices of Fuels and Power Divisions)

The Dry Quenching of Coke, WILLIAM O. RENKIN
Recovery of Fly Ash From Pulverized-Fuel Stacks by Use of Stack Sprays, J. W. MACKENZIE

MANAGEMENT

(Auspices of Management Division with American Management Association Cooperating)

Five-Minute Talk on Safety—Is Management Responsible for Industrial Casualties? GEORGE OPP
Management of the Small Manufacturing Plant: Its Characteristics and Advantages, CROSBY FIELD
Management of the Large Manufacturing Plant: How to Retain the Advantages of the Small Plant, A. B. REYNDERS

MECHANICAL SPRINGS

(Auspices of A.S.M.E. Special Research Committee on Mechanical Springs)

Stresses and Deflections in Helical and Spiral Torsional Springs as Affected by Curvature. Progress Report No. 6 of Special Research Committee on Mechanical Springs, M. F. SAYRE
Further Research on Helical Springs of Round and Square Wire, ARTHUR M. WAHL

Thursday Morning, June 12

CENTRAL STATION POWER

(Auspices of Power Division)

Comparative Performance of a Large Boiler Using Oil and Natural-Gas Fuels, FRANK G. PHILO
Comparative Performance of a Pulverized-Coal-Fired Boiler Using Bin System and Unit System of Firing, ARTHUR E. GRUNERT

AERONAUTICS

(Auspices of Aeronautic Division)

Air Transportation, PAUL GOLDSBOROUGH
Automotive Methods and Practices Involved in Aircraft Engines, O. E. SZEKELY
Motorless Flight, DONALD F. WALKER

EDUCATION AND TRAINING

(Auspices of Committee on Education and Training for the Industries)

Five-Minute Talk on Safety—The Prevention of Industrial Casualties Through Instruction in Foremen's Schools, Rotative Safety Committees, etc., R. F. THALNER
Training Aeronautical and Automotive Service Mechanics, A. D. ALTHOUSE
The Training and Recruitment of Auto Mechanics Through Factory Sources, WM. F. RASCHE.

French Lick Springs Meeting

MILD October weather, a famous health and pleasure resort set in the colorful hills of Southern Indiana, combined with excellent technical sessions and a splendid entertainment program, made the meeting of the Society held at French Lick, Ind., October 13–15, 1930, a most delightful event. Except for a conference of the Committee on Local Sections on Sunday, no committee meetings were scheduled.

The Student Session arranged for Monday afternoon proved to be a most interesting technical event. Papers were presented by representatives of Armour Institute of Technology on "The Power Industry;" University of Cincinnati, "Cooperative Education;" University of Illinois, "Research in Mechanical Engineering;" University of Louisville, "Cooperative Education;" Purdue University, "Instruction in Flying to Engineering Students;" Rose Polytechnic Institute, "Mechanical Engineering in the Coal Industry;" and Washington University, "Heat Treatment of Nickel Steel Welds." A prize of $25 offered by William A. Hanley, Manager of the Society, for the best contribution to this Session, was awarded to Allen G. Stimson, representative of Rose Polytechnic Institute. Mr. Stimson gave a concise statement covering the reasons for mechanization in the coal industry and its results.

At a luncheon for students with Council members on Monday Dr. C. E. Grunsky, President of the American Engineering Council, delivered a most inspiring message.

TECHNICAL PROGRAM

The titles and authors of papers presented at the French Lick Meeting are given in the following summary of the technical program.

Monday Morning, October 13

AUTOMOTIVE

Engineering Problems of Modern Motor Cars, WM. G. WALL
The Diesel Engine for Automobiles, C. L. CUMMINS

Monday Afternoon, October 13

STUDENT SESSION

See paragraph above.

Tuesday Morning, October 14

MANUFACTURING

Developments in the Conveyor Field, HENRY R. GOTTHARDT
Psychometry and Some Common Effects of Air Conditioning on Materials, D. C. LINDSAY
Machine Tool Milestones, Past and Future, SOL EINSTEIN

Wednesday Morning, October 15

GLASS AND STONE INDUSTRY

High-Burned Kaolin Refractories, F. H. NORTON
Engineering Problems in the Stone Industry, H. S. BRIGHTLY
Limestone Research, H. C. PEFFER

ENTERTAINMENT

The Entertainment Committee provided a varied program, including a trip to the Marengo Caves, an inspection tour of the Bedford Limestone Quarries, a miniature-golf tournament for the ladies, tournaments on the regular golf courses for both ladies and men, a bridge tournament for the ladies, and a horseshoe pitching contest for the men.

An informal dinner on Monday evening and the banquet Tuesday evening brought very valuable contributions from outstanding engineers in the Middle West. William A. Hanley painted a graphic picture of industry today as compared with the old hit-and-miss methods of manufacturing and safety of a generation ago. Dr. Allen D. Albert, assistant to the president of the Chicago World's Fair Centennial Celebration, said that the progress of the past century is the clear product of science, therefore, the motif of Chicago's celebration in 1933 would be "Science."

Dr. Edward C. Elliott, President of Purdue University, addressed the banquet gathering on "The Sixth Estate," which he defined as those who recruit the leadership of our day. "Engineers must assume the responsibility of preparing these young men not for jobs, but for the joy of serving humanity," he declared. "They must be the masters of machines and must not allow machines to master them. Fitness for the job must be the creed of the craft."

Fifty-First Annual Meeting

HELD at a time when the business depression was perhaps being most keenly felt throughout the country, the 1930 Annual Meeting of the Society at New York, December 1–5, was surprisingly well attended, the registration being the largest ever recorded, 2562. Those who established this record must have found their time well spent. The program was not only unusually varied and worth while, but it was in many respects peculiarly suited to the current conditions in industry. The stabilization of employment and the engineer's relation to this and kindred problems were the subjects of several conferences and addresses. Technical sessions and committee meetings stressed the subjects of research, standardization, accident prevention, and industrial management. Conferences of the Council and Local Section and Student Branch delegates studied ways in which the Society might bring aid to the solution of these problems.

Conferences on Unemployment

At a meeting of the Council on Monday morning, December 1, L. W. Wallace, executive secretary of the American Engineering Council, brought to the Society an invitation to undertake a study of what industry had done in the past and was doing to stabilize employment. The American Engineering Council had been asked by Col. Arthur S. Woods, chairman of President Hoover's Emergency Committee for Employment, to sponsor such a study. Colonel Woods addressed the Council of the Society and in the afternoon presented the problem to the members of the Society at a special conference.

The attitude of the Council toward the request for cooperation was expressed in the following resolution, which was endorsed by the Local Sections Conference:

Voted: That The American Society of Mechanical Engineers pledges its full cooperation and assistance in response to the request of Colonel Arthur Woods, Chairman of the President's Emergency Committee for Employment, transmitted by the American Engineering Council. The Society will undertake a program of:

(1) Urging industry to adopt measures now to relieve the winter emergency; and
(2) Compiling data as to effective policies and methods used to deal with the general question of irregular employment; and
(3) Assisting in all other practical ways.

The Council authorized the President of the Society to appoint a committee to organize and direct the work.[1]

A second important conference on the stabilization of employment in industry was held on Wednesday. This conference, arranged by the Management Division of the Society with the cooperation of the American Management Association, was attended by more than two hundred executives, engineers, and members of various commissions studying the employment problem. The presentation of three papers was followed by general discussion. The industrial depression, with its acute unemployment problem, was recognized by the conference as one solely of an economic nature. The causes that stood out clearly were summarized as being: (1) A certain amount of over-production; (2) strenuous but costly efforts to stimulate increased consumption; (3) unintelligent price cutting; (4) excessive wastes in distribution; (5) a general alarm over the acuteness of the situation that causes industrial plants to undertake drastic retrenchment; (6) a consequent reaction on the public that reduces sales and consumption; and (7) a repetition of the vicious cycle on decreasingly smaller production schedules that continuously reduce employment.

[1] Announcement of the personnel of this committee was made by President Roy V. Wright on December 13, as follows: Ralph E. Flanders, chairman, Dexter S. Kimball, Ely C. Hutchinson, J. W. Roe, Col. C. H. Crawford, and Col. W. A. Starrett, with President Wright and Secretary Rice as members ex-officio.

Social Engineering

Addresses on President's Night and at the Annual Dinner on Wednesday brought new light to the relation of the engineer to his fellow-men and their problems. On the former occasion Ralph E. Flanders, manager of the Jones & Lamson Machine Co., Springfield, Vt., and vice-president of the A.S.M.E., and Dr. Wesley C. Mitchell, director of the National Bureau of Economic Research, New York, delivered addresses on the subject of "Engineering, Economics, and the Problem of Social Well-Being," in which engineers were urged to join more fully with other professions working toward the solution of social problems. Mr. Flanders presented the point of view of the engineer, while Dr. Mitchell gave that of the economist.

Prof. Elliott Dunlap Smith, director of industrial investigations of the Institute of Human Relations and professor of industrial engineering at Yale University, in his address entitled "The Engineer Encounters Human Nature," at the Annual Dinner, presented the social responsibility of the engineer in another way, that of adapting mechanism to man.

"Talking With an Audience"

For many years the A.S.M.E. has been making a constructive and sincere attempt to improve the conduct of its technical sessions and the manner in which papers are presented. In this connection a series of three talks on "Talking with an Audience" were given by Dr. S. Marion Tucker, head of the department of English at the Polytechnic Institute of Brooklyn, on Tuesday, Wednesday, and Thursday mornings preceding the technical sessions. These talks were of a practical nature and very favorably received.

Exhibition of Art by Engineers

An event entirely new to programs of the A.S.M.E. was the exhibition of art by engineers. The formal opening of the exhibition on Monday evening was preceded by an hour of music by the "Bridge Engineers' Trio," composed of John E. Greiner, violin; Otis E. Hovey, flute; and Ralph Modjeski, piano, and an address by Dean Robert L. Sackett, of Pennsylvania State College, on "Art as an Engineer's Hobby." More than two hundred exhibits were on display in the galleries of the fourth floor of the Engineering Societies Building, and included sculpture, paintings, prints, line drawings, and photographs by more than seventy professional engineers. L. P. Alford, vice-president of The Ronald Press Company, New York, and past vice-president of the A.S.M.E., was chairman of the committee in charge of the exhibition.

Honors and Awards

The Fifty-First Annual Meeting was distinguished also by a number of important awards.

On President's Night, Elihu Thomson was made an honorary member of the A.S.M.E. Professor Thomson was presented by Ambrose Swasey, honorary member and past-president, A.S.M.E., and honorary membership was conferred by Col. Paul Doty, vice-president, A.S.M.E., acting for President Charles Piez.

The dinner on Wednesday evening was the occasion of the presentation of the John Fritz Gold Medal to Admiral David Watson Taylor "for outstanding achievement in marine architecture, for revolutionary results of persistent research in hull design, for improvement in many types of warships, and for distinguished service as chief constructor of the United States Navy during the World War." Lincoln Bush, chairman of the John Fritz Medal Board of Award, presided. The address on the career and achievements of Admiral Taylor was made by Walter M. McFarland, past-president of the Society of Naval Architects and Marine Engineers, and past vice-president of the A.S.M.E., and the medal was presented by Bancroft Gherardi, chairman of the board which made this award and past-president of the American Institute of Electrical Engineers.

At the dinner also special badges were presented by Charles E. Gorton, acting for President Piez, to those who had been members of the Society for fifty years, as follows:

Ellwood Burdsall	Henry Marx
John W. Cloud	H. F. J. Porter
J. S. Coon	Francis H. Richards
P. B. De Schweinitz	Albert W. Smith
Thomas A. Edison	Ambrose Swasey
Auguste A. Goubert	Edward N. Trump

Walter Wood

At the business meeting on Monday evening the Awards Committee, represented by Dean Arthur M. Greene, Jr., and Prof. H. L. Seward, conferred the following awards.

The Melville Medal, established in 1914 by the bequest of Rear-Admiral George W. Melville, honorary member and past-president of the Society, for an original paper or thesis of exceptional merit, was presented to Herman Diederichs, director of the Sibley School of Mechanical Engineering, Cornell University, and William D. Pomeroy, vice-president and general manager of Goulds Pumps, Inc., Seneca Falls, N. Y., as co-authors of a paper on "The Occurrence and Elimination of Surge or Oscillating Pressures in Discharge Lines from Reciprocating Pumps."

The Junior Award, an annual cash prize of $50, together with an engraved certificate, established in 1914 from a fund created by Henry Hess, past vice-president of the Society, for the best paper or thesis submitted by a junior member, was bestowed on Ed Sinclair Smith, Jr., of the Builders Iron Foundry, Providence, R. I., for his paper on "Quantity-Rate Fluid Meters."

Student Awards, two annual cash awards of $25 each, were also established in 1914 from a fund created by Henry Hess, to be presented with engraved certificates for the best papers or theses submitted by student associates. One of these for 1930 was presented to Gerard Eden Claussen, Polytechnic Institute of Brooklyn, class of 1930, and a graduate student at the Massachusetts Institute of Technology, for his paper on "High-Temperature Oxidation of Steel."

The second Student Award went to Harold L. Adams and Richard L. Stith, University of Washington, class of 1930, for their paper on "A Wind Tunnel for Undergraduate Laboratory Experiments."

The Charles T. Main Award for 1930 was conferred upon Jules Podnossoff, Polytechnic Institute of Brooklyn, class of 1931, for his paper on "The Value of the Safety Movement in the Industries." This prize of $150, given annually, was established in 1919 from a fund created by Charles T. Main, past-president of the Society, to be awarded to a student of engineering, preferably a member of a Student Branch of the Society, for the best paper within the general subject of "The Influence of the Profession upon Public Life."

The Annual Dinner

The Annual Dinner, held at the Hotel Astor, was attended by nearly one thousand members and guests. For several years past it has been customary to have the women attending the Annual Dinner seated at tables in the balcony. This year women were seated with the men on the main floor, a change in arrangements which brought expressions of approval from many.

The formal program of the evening was in charge of Ely C. Hutchinson, a manager of the Society, as toastmaster. Mr. Hutchinson presented Mr. Rice, secretary of the Society, who read the names of those who had become members during the year, and called upon them to rise in their places. He then introduced Conrad N. Lauer, vice-president of the Society, who delivered the charge to these new members.

After the presentation of the fifty-year badges and the address by Dr. Smith the floor was cleared for dancing.

Conferences and Committee Meetings

At the Monday meeting of the Council approval was given of the petition of the members in Eastern Connecticut for a Local Section with headquarters at Norwich, Conn., the territory to include the counties of Tolland, New London, and Windham in Connecticut, and Westerly Township in Rhode Island.

The Council also approved the establishment of a Student Branch at Harvard University.

The Local Sections held conferences on Monday and Tuesday and met with the Council for luncheon on Monday. Delegates were present from all of the Sections except Susquehanna and Utica. Group meetings were held on Tuesday morning for the selection of candidates for the Nominating Committee of the Society for 1931–1932. The personnel recommended by the groups was approved at the Tuesday afternoon conference.

At the general conferences on Monday and Tuesday representatives of several standing committees addressed the delegates and many subjects of common interest were discussed, including financing Local Sections, cooperation with the Society's Committee on the Economic Status of the Engineer, licensing and registration of engineers, and the relation of Local Sections to Student Branches.

The representatives of the Student Branches of the Society met with the Council at a luncheon on Wednesday, after which a conference was held for the presentation of several papers as listed in the accompanying technical program. The honorary chairmen of the Student Branches met at a luncheon on Thursday.

During the Annual Meeting the technical committees held forty-three meetings on Research, Standards, Power Test Codes, Boiler Code, and Safety. These meetings had an attendance of more than five hundred. Several of the Standing Committees of the Society held conferences, as did the majority of the executive committees of the Divisions.

Two important conferences were held relating to new Divisional work. A conference on Wednesday afternoon for the consideration of a Process Division resulted in the formation of a Process Industries Committee. A program of cooperation with the American Institute of Chemical Engineers was discussed with three representatives of that society, and an agreement was reached whereby the two societies would have joint meetings and papers committee covering the process and chemical industries. The programs for meetings of the process industries groups of the two societies would be worked out by this joint committee and each society would cooperate in the meetings of the other society.

Following the joint technical session with the A.S.R.E. a conference was held to discuss the formation of an Air Conditioning Division. After some discussion it was suggested by W. H. Carrier, chairman of the conference, that a division on thermal engineering or heat transmission be formed. It was

voted to ask the American Society of Refrigerating Engineers, the American Society of Heating and Ventilating Engineers, the American Institute of Chemical Engineers, and the A.S.M.E. each to appoint two representatives to meet to discuss cooperative action on heat transmission and the advisability of the formation of an A.S.M.E. division on this subject; the activities of such a division possibly to be supervised by a joint committee so as to assure more complete cooperation.

Business Meeting

At the business meeting on Monday evening the annual report of the Council and its standing committees was presented by Mr. Rice, Secretary of the Society, and the tellers reported the adoption through letter ballot of the members (by a vote of 4762 to 1376) of the amendment to the Constitution regarding initiation fees, as presented at the Detroit Semi-Annual Meeting.

After the conferring of awards the meeting was adjourned until Tuesday evening, when the report of the Local Section delegates naming the 1931–1932 Nominating Committee was received, as follows:

Group I: S. J. Teller, West Hartford, Conn.; R. E. Newcomb, Holyoke, Mass., first alternate; F. S. Clark, Boston, Mass., second alternate
Group II: C. P. Tolman, New York, N. Y.; A. A. Adler, New York, N. Y., alternate
Group III: Harte Cooke, Auburn, N. Y.; Alfred Iddles, Philadelphia, Pa., first alternate; F. A. Allner, Baltimore, Md., second alternate
Group IV: W. R. Woolrich, Knoxville, Tenn.; D. E. Kehoe, Savannah, Ga., alternate
Group V: A. E. White, Ann Arbor, Mich.; W. M. Taylor, Indianapolis, Ind., alternate
Group VI: W. C. Lindemann, Milwaukee, Wis.; C. A. Herrick, Minneapolis, Minn., alternate
Group VII: Dennistoun Wood, San Francisco, Calif.; A. J. Dickie, San Francisco, first alternate; R. L. Mahon, San Francisco, second alternate

The report of the tellers of election of officers for 1931–1932 was also heard at the Tuesday night meeting, as follows:

President: Roy V. Wright
Vice-Presidents: Harvey N. Davis, William A. Hanley, Thomas R. Weymouth
Managers: W. L. Batt, H. L. Doolittle, H. L. Whittemore

These officers were installed at a meeting of the Council on Friday morning.

Technical Sessions

Simultaneous technical sessions were held morning and afternoon of every day starting Monday and ending Friday. At these sessions, which numbered 32, 67 papers and 19 reports were presented. The usual joint meeting of the A.S.R.E. and the A.S.M.E. was held on Friday afternoon and was presided over by W. H. Carrier, a member of both societies.

On Wednesday afternoon there was a joint session of the Wood Industries Division with the American Society of Safety Engineers. The Rudolph Diesel award for the best paper delivered at the 1930 Oil and Gas Power National Meeting was presented to Geo. J. Dashefsky, assistant mechanical engineer, Diesel Engine Section, U. S. Navy Yard, Brooklyn, at the Oil and Gas Power session on December 4.

The complete program of the technical sessions follows:

Monday Morning, December 1

Lubrication Engineering

(Auspices of Petroleum Division)

Crane Lubrication, Eustis H. Thompson
The Work Factor of Lubricating Oil, James G. O'Neill
Evaluation of Steam Turbine Oil Stability, Clifford M. Larson

Applied Mechanics (I)

(Auspices of Applied Mechanics Division)

Determination of Stresses in Rotating Disks of Conical Profile, F. C. Rushing
Stresses in Retaining and Centering Rings for Turbine-Generator Rotors, R. Patterson and D. H. Harms

Monday Afternoon, December 1

Materials Handling (I)

(Auspices of Materials Handling Division)

Handling Materials at the Postum Company, P. P. Pratt
Material Handling in the Shoe Industry, Kenneth D. Hamilton
Materials-Handling Methods in the Fisk Tire Plant, Charles Edgar Maynard

Symposium on Industrial Accident Prevention

(Auspices of Standing Committee on Safety)

Economic Aspects of Industrial Casualty Reductions, L. W. Wallace
Engineering Revision an Essential Factor in Accident Prevention, Lucian W. Chaney
Management's Responsibility for Industrial Accidents, L. P. Alford

Applied Mechanics (II)

(Auspices of Applied Mechanics Division)

Plastic Torsion, A. Nadai
Vibrations of Railway Bridges, J. N. Goodier

Tuesday Morning, December 2

Machine-Shop Practice (I)

(Auspices of Machine-Shop Practice Division)

A Survey of Surface Quality Standards and Tolerance Costs Based on 1929–1930 Precision-Grinding Practice, R. E. W. Harrison, with appendix by C. B. Sawyer
Transmission of Torque by Means of Press and Shrink Fits, J. W. Baugher, Jr.
Progress Report of Machine Shop Practice Division, presented by C. de Zafra

Railroad (I)

(Auspices of Railroad Division)

Progress Report of Railroad Division
High-Pressure and High-Temperature Steam for Locomotives, C. F. Hirshfeld
The Stug System of Pulverized Fuel Firing on Locomotives, R. Roosen

Materials Handling (II)

(Auspices of Materials Handling Division)

Progress Report of Materials Handling Division, presented by George E. Hagemann
Materials Handling in Warehouses, N. E. Whittemore

Hydraulics

(Auspices of Hydraulic Division)

Progress Report of Hydraulic Division, presented by Byron E. White
Federal Relations to Water-Power Development, Frank E. Bonner
A Method for Standardization of Centrifugal Pumps, Jos. S. Stepanov

Tuesday Afternoon, December 2

Railroad (II)

(Auspices of Railroad Division)

Research Relating to the Action of 4-Wheel Freight-Car Trucks, T. H. Symington

Machine-Shop Practice (II)

(Auspices of Machine-Shop Practice Division)

The Uses of 16 Mm. Movies in Industry, Maynard L. Sandell
The Application of Spectroscopic Apparatus to Industry, Charles C. Nitchie

Materials Handling (III)

(Auspices of Manufacturers Committee of Materials Handling Division)

Report of Subcommittee on Classification of Materials-Handling Equipment and Nomenclature, G. L. Morehead

Report of Subcommittee on Performance Standards of Locomotive Cranes and Crawlers, H. H. PERRY
Report of Subcommittee on Capacity of Containers, W. E. FARRELL
Report of Subcommittee on Cross-Reference Index for Equipment and Materials Handling, M. W. POTTS
Cooperative Research, BRINTON WELSER
Report on Educational Possibilities, C. B. CROCKETT

INDUSTRIAL POWER

(Auspices of Power Division)

Engineering Aspects of Interchange of Power with Industrial Plants B. F. WOOD
Combined Heat and Power Supply in Industrial Plants, W. F. RYAN

Wednesday Morning, December 3

FUELS

(Auspices of Fuels Division)

Progress Report of Fuels Division, T. A. MANGELSDORF
Heat Absorption in Water-Cooled Furnaces, WM. L. DEBAUFRE
Radiant Heat Transmission between Surfaces Separated by Non-Absorbing Media, H. C. HOTTEL

STABILIZATION OF EMPLOYMENT IN INDUSTRY

(Auspices of Management Division, with cooperation of American Management Association)

Discussion of Manufacturing in Advance of Orders in Seasonal Industries, EDWIN S. SMITH
Discussion of Unemployment—Its Causes, Palliation, and Prevention, ROYAL MEEKER
Discussion of Employment Stabilization in the Proctor and Gamble Company, HARVEY C. KNOWLES

GENERAL

Machining Properties of Some Cold-Drawn Steels, O. W. BOSTON
Frictional Resistance and Flexibility of Seamless-Tube Fittings Used in Pipe Welding, SABIN CROCKER and ARTHUR MCCUTCHAN

TEXTILES

(Auspices of Textile Division)

Progress Report of Textile Division
Special Applications of Electric Motors in Cloth-Finishing Plants, A. M. MACCUTCHEON
Lubrication of Textile Machinery, L. A. BAUDOIN

Wednesday Afternoon, December 3

APPRENTICE TRAINING

(Auspices of Committee on Education and Training for the Industries)

Apprentice Training in Virginia, C. F. BAILEY
Apprentice Training Movement in Wisconsin Industry, HAROLD S. FALK
Opportunities for Aviation Training, JOSEPH S. MARRIOTT

SAFETY AND WOOD INDUSTRIES

(Joint Session of Wood Industries Division with American Society of Safety Engineers)

Dust Explosions, With Special Reference to Woodworking Industries, HYLTON R. BROWN
Research in Wood Products, JAMES W. LAWRIE
Progress Report of Wood Industries Division, presented by THOMAS D. PERRY

STEAM TABLES RESEARCH

(Auspices of A.S.M.E. Special Research Committee on Thermal Properties of Steam)

Additional Volume Data for Superheated Steam, L. B. SMITH and F. G. KEYES
Some Final Values for Saturated and Superheated Steam, F. G. KEYES and L. B. SMITH
Report of the Progress in Steam Research at the Bureau of Standards, N. S. OSBORNE
Thermal Properties of Compressed Liquid Water, J. H. KEENAN

STUDENT BRANCH CONFERENCE

Opportunities in Engineering, W. A. HANLEY
Engineers and Engineering in Foreign Lands, CHARLES E. GORTON
Engineering and Government, L. W. WALLACE

Thursday Morning, December 4

CENTRAL STATION POWER

(Auspices of Power Division)

Operating Experiences, Deepwater Station, K. M. IRWIN
Operation of the Holland Station, E. M. GILBERT

MANAGEMENT

(Auspices of Management Division, with cooperation of American Management Association)

American Management in Europe, WALLACE CLARK
Progress Report of Management Division, presented by C. W. LYTLE

AERONAUTICS

(Auspices of Aeronautic Division)

Airplane Cabin Engineering, PIERRE FREYSS and JOHN F. HARDECKER
Airplane Instrument Vibration (Report of A.S.M.E. Special Research Committee on Airplane Vibration with Special Reference to Instruments), FREDERICK K. TEICHMANN
Progress Report of Aeronautic Division, presented by C. H. COLVIN

CUTTING METALS

(Auspices of A.S.M.E. Special Research Committee on Cutting of Metals)

Tool-Steel Tools, A. H. D'ARCAMBAL
Cemented Tungsten Carbide as Applied to Cutting Tools, L. J. ST. CLAIR
Haynes Stellite Cutting Tools, W. A. BECKER, E. E. GORDON, and W. A. WISSLER

Thursday Afternoon, December 4

OIL AND GAS POWER

(Auspices of Oil and Gas Power Division)

Progress Report of Oil and Gas Power Division, presented by M. J. REED
Some Features of the Long-Distance Transportation of Natural Gas, GEO. I. RHODES and EDGAR G. HILL
A Simple Method for the Calculation of Natural Frequencies of Torsional Vibration, FREDERIC P. PORTER

BOILER FURNACE REFRACTORIES

(Auspices of A.S.M.E. Special Research Committee on Boiler Furnace Refractories)

Comparative Resistance of Refractories to Coal-Ash Slags, R. K. HURSH
Action of Slags on Firebrick and Boiler Furnace Settings, T. A. KLINEFELTER and E. P. REXFORD
Furnace-Gas Compositions and Temperatures in Underfeed-Stoker-Fired Boilers, and Their Effect on Boiler Settings, ALBERT C. PASINI and EDWARD M. SARRAF

Friday Morning, December 5

SYMPOSIUM ON FLAT-BED CYLINDER PRESSES (I)

(Auspices of Printing Industries Division)

Some Problems in Standardization, FRED S. ENGLISH
Design of the New Harris Automatic Two-Color Flat-Bed Press, ALFRED S. HARRIS
Progress in Printing, W. S. HUSON

PROPERTIES OF METALS

(Auspices of Joint Research Committee on Effect of Temperature on Properties of Metals)

Properties of Non-Ferrous Alloys at Elevated Temperatures, C. L. CLARK and A. E. WHITE
Comparative Physical Properties of Chromium-Nickel, Chromium-Manganese, and Manganese Steels, C. L. CLARK and A. E. WHITE

LUBRICATION RESEARCH

(Auspices of A.S.M.E. Special Research Committee on Lubrication)

On Problems in the Theory of Fluid-Film Lubrication, with an Experimental Method of Solution, ALBERT KINGSBURY
Lubrication Research Activities (Fifth Report of A.S.M.E. Special Research Committee on Lubrication) presented by MAYO D. HERSEY and A. E. FLOWERS

Friday Afternoon, December 5

SYMPOSIUM ON FLAT-BED CYLINDER PRESSES (II)

(Auspices of Printing Industries Division)

Five-Minute Talk on Safety, ROBT. R. ELBERTY
Sizes and Tolerances for Metal Fits, C. R. REIMAN
Design of the Miller Simplex Automatic Two-Revolution Cylinder Press, A. W. BARRETT
Forces in Connection With the Reciprocating Beds of Flat-Bed Cylinder Printing Presses, B. D. STEVENS and H. E. GOLBER

MECHANICAL SPRINGS

(Auspices of A.S.M.E. Special Research Committee on Mechanical Springs)

Elastic and Inelastic Behavior in Spring Materials (Progress Report No. 7 of Special Research Committee on Mechanical Springs), M. F. SAYRE
Design of a Conical Spring with Coils of a Uniform Slope (Progress Report No. 8 of Special Research Committee on Mechanical Springs), Jos. B. REYNOLDS and O. B. SCHIER

REFRIGERATION

(Joint Session with The American Society of Refrigerating Engineers)

The Effect of Humidity on the Heat Transmission of Galvanized Pipe (*Contributed by A.S.R.E.*), W. R. WOOLRICH
Psychometry and the Effects of Air Conditions on Some Familiar Products (*Contributed by A.S.M.E.*), DANIEL C. LINDSEY

COLLEGE REUNIONS AND POWER SHOW

As usual, Thursday evening was set aside for the reunions of various colleges. A number of college alumni associations held dinners on that date, and other groups met for luncheon or dinner during the week.

The Ninth National Exposition of Power and Mechanical Engineering was held at the Grand Central Palace during the week and afforded members and their guests an opportunity to view the most recent developments in that field.

EXCURSIONS

The excursions scheduled were exceptionally well attended. They included trips to the *Bremen* and the *Olympic;* the Westinghouse Lighting Institute; the Hell Gate Power Station; the Hudson Avenue Generating Station; the Western Electric Company's Kearny plant; the East River Generating Station; the plant of the G. J. Tagliabue Mfg. Co.; the Holland Tunnels; the Pioneer Instrument Company; the United States Navy Yard; and the laboratory of the St. John X-Ray Service Corporation.

THE WOMEN'S PROGRAM

A most efficient committee of women from the A.S.M.E. Woman's Auxiliary established headquarters in the lobby of the building and took splendid care of all their many visitors. In addition to the evening affairs which were part of the general program, there were several events especially for the women. On Tuesday at the Astor Hotel at the annual luncheon of the Auxiliary, Dr. Lillian M. Gilbreth, a member of President Hoover's Emergency Committee for Employment, gave a short talk in which she sketched briefly the part women should play and were playing to bring about normal conditions.

On Wednesday there was a special excursion to the new Riverside Church, followed by luncheon either at the International House or the Engineering Women's Club, while later in the afternoon a "Library Talk," led by Mrs. Frank Jewett, was given at the Engineering Women's Club on the book "Humanity Uprooted," by Maurice Hindus. Thursday morning's excursion to the Colgate-Palmolive-Peet Company in Jersey City was exclusively for the women and was particularly enjoyed, while in the afternoon the annual tea was held at the Museums of the Peaceful Arts, where a very enjoyable program was presented, with talks and motion pictures, and an opportunity was given to see a special exhibit of the works of Dr. Elmer A. Sperry, past-president of the Society.

An enjoyable visit to Princeton University under the personal guidance of Dean Arthur M. Greene, Jr., closed the trips on Friday.

Meetings of the Professional Divisions

Aeronautic Division

PITTSBURGH, PA., MARCH 12, 1930

Several valuable papers were presented at the Pittsburgh Aero Conference held at the William Penn Hotel on March 12, 1930. The meeting was sponsored jointly by the A.S.M.E. Aeronautic Division and the Pittsburgh Local Section, with the cooperation of a newly founded Aeronautic Section of the Engineers' Society of Western Pennsylvania. The conference consisted of morning and afternoon sessions with an interesting luncheon meeting.

TECHNICAL PROGRAM

The titles and authors of papers are given in the following summary of the program:

Wednesday Morning, March 12

Development of the Drop-Forged Metal Propeller, FRANK W. CALDWELL
New Aircraft Instruments, S. J. ZAND and FLOYD B. NEWELL
New Developments in Airport Lighting, H. C. RITCHIE

Wednesday Luncheon Meeting, March 12

The Future of Air Transport, THOMAS LANPHIER
Safety in Aircraft, HAROLD F. MARTIN

Wednesday Afternoon, March 12

Metalizing the Airplane, H. V. THALDEN
Some Aspects of All-Metal Airplane Construction, WELLWOOD E. BEALL
Some Aspects of Airplane Design, SCHUYLER KLEINHANS
Trend in Aircraft-Engine Design, C. H. SCHOWALTER
The Radiophone in Air Transport, R. H. FREEMAN

Aeronautic Division

DAYTON, OHIO, MAY 19–22, 1930

The Fourth National Technical Aeronautic Meeting of the Aeronautic Division, held at Dayton under the auspices of the Dayton Section, May 19 to 22, 1930, attracted several hundred members and guests. A most unusual feature of the meeting were the remarkable arrangements made at Wright Field for the inspection of its laboratories. Interesting pieces of machinery were labeled clearly and many of the labels carried photographs of apparatus in different positions so as to convey quickly as much engineering information as possible.

WRIGHT FIELD INSPECTION TOURS

The tours at the Field gave a choice between one general inspection trip and four special branch visits. The Aeroplane Branch provided some very interesting propeller and wind-

tunnel test explanations. The Power-Plant Branch had a number of engines on test. The Materials Branch was instructively labeled and proved unusually interesting. At the Equipment Branch visitors were entertained with the "flight tutor."

Flying Demonstration

The flying demonstration on Friday, at Wright Field, was unique in the history of aeronautics. The arrangements were carried through with military precision and thoroughness. On the Field was placed a double line of various types of airplanes, both for Government service and commercial use. It was an exceptional ground display, and the guests were privileged to study the planes and question the mechanics. When the flying program started, Lieut. S. P. Mills announced through a special radio broadcaster information of engineering interest and value about each airplane as it took the air. Among the unusual demonstrations was that of pursuit maneuvering by the "Boeing P-12," and the dropping of three parachutes simultaneously, giving decisive proof of the dropping qualities of each.

Dinner Program

The dinner proved one of the high spots of the meeting. The favor was an autographed composite photograph of the original Wright Brothers' plane in its first flight, with pictures of Orville and Wilbur Wright inserted in the upper corners. The photograph had been autographed by Orville Wright, the guest of honor at the dinner, and given to the Dayton Section of the Society for this purpose.

The speech of Captain Sir Hubert Wilkins was of unusual interest, as he told of his experiences in the Anarctic with Dr. Stefansson on foot, and then of his experiences with the airplane. General B. D. Foulois described his first cross-country flight with Orville Wright in 1909, when the Wright plane first passed the Government tests. The other banquet speaker was Casey Jones, president of the Curtis Flying Service and well-known racing pilot, who discussed many interesting developments in civil aviation. Chas. W. Ripsch, chairman of the Dayton Section, opened the dinner with a few remarks and introduced Charles F. Kettering, who was the toastmaster.

Technical Program

The number of papers presented was very large and the discussion noteworthy. The titles of the papers and names of the authors were as follows:

Monday Morning, May 19

What the Airplane Can Do in Central and South America, Roy V. Wright
Economic Aspects of the Rigid Airship, Carl B. Fritsche

Monday Afternoon, May 19

Design of Airplane from the Point of View of Cheap Production, Russell F. Hardy
Production Methods in Airplane Construction, R. S. Damon
Airplane Design, Manufacture, and Sales, Commercial vs. Military, Rex B. Beisel
Reduction of Airplane Production Costs, J. Don Alexander

Monday Evening, May 19

Accomplishments and Possibilities of Aerial Photography, A. W. Stevens

Tuesday Morning, May 20

German Metal Airplane Construction, Herbert Wagner
Airplane Wing Trussing, Richard Mock
Engineering Organization in the Airplane Factory, E. Molloy

Tuesday Afternoon, May 20

Fuel and Lubricants Session

The High Performance Gasoline Aircraft Engine and Its Fuel and Oil Problems, S. D. Heron
Some Aspects of Aircraft Lubrication, B. E. Sibley
The Present Status of Superchargers for Aviation Engines, Sanford A. Moss

Aerodynamics Session

Practical Airplane Performance Calculations, Michael Watter
The Airscrew with Minimum Loss of Energy, Enrico Pistolesi

Wednesday Morning, May 21

Silencing the Airplane, Hugh L. Dryden
The General Problem of Fire Hazard in Aircraft, C. G. McCord
Summary of Aerodynamics of Leonardo Da Vinci, R. Giacomelli

Wednesday Afternoon, May 21

Some Characteristics of Light Alloys for Aeronautics, H. W. Gillett
Aluminum Alloys for Pistons and Air-Cooled Cylinder Heads for Aircraft Engines, A. J. Lyon

Thursday Morning, May 22

The Artificial Horizon, Elmer A. Sperry, Jr.
The Economics of Airplane Transportation, Erich Offerman
Design and Development of Transatlantic Seaplane, E. Rumpler
Principles and Development of Air Law, André Henry-Courannier

Thursday Afternoon, May 22

Trend in Aircraft-Engine Development, Harold Caminez
Vibration Characteristics of Aircraft-Engine Crankshafts, F. L. Prescott
Installation of Radial Cooled Engines, P. B. Taylor

Aeronautic Division

SEATTLE, WASH., MAY 28 AND 29, 1930

The Aeronautics Meeting at Seattle, Wash., on May 28 and 29, 1930, was sponsored jointly by the Aeronautic Division and the Western Washington Section of the Society, and was held with the cooperation of the department of aeronautics of the University of Washington. The meeting had an average attendance at technical sessions of about 100, with a total registration of 139.

An informal luncheon was held on Wednesday in one of the rooms of the Home Economics Building of the University, after which trips were arranged to the plant of the Boeing Airplane Company and to the Municipal Airport. On Thursday a trip was made to the Sand Point Aviation Field.

Speakers at Dinner

A particularly enjoyable dinner was held Wednesday evening at the Seattle Yacht Club with E. O. Eastwood presiding as toastmaster. W. L. Dudley, vice-president and chief engineer of the Western Blower Company, Seattle, spoke on behalf of the A.S.M.E., while Commander J. D. Price represented the Navy, and Colonel H. C. Fiske the Army, in talks on aviation. Dean Leslie Ayer, of the University of Washington, took for his subject "Air Rights; Past, Present, and Future."

The papers presented at the technical sessions were as follows:

Wednesday Morning, May 28

Management and Operation of a Large Airport, W. D. Waterman
Air-Transport Management, D. W. Tomlinson
Air Design and Construction, W. L. Lewis

Thursday Morning, May 29

The Layout and Design of Modern Airplane Plants, G. W. Plaisted
Flying from the Private Owner's Standpoint, Earle Ovington
Interesting Engineering Problems in the Operation of Air Transports, J. C. Canney

Aeronautic Division

CHICAGO, ILL., AUGUST 25, 1930

A notable program of the Chicago Section with the Aeronautic Division cooperating was held on August 25, 1930, during

the 1930 National Air Races at the Curtiss-Reynolds Airport, Glenview, Ill., one of Chicago's suburbs. A morning technical session was held in the Airport Restaurant, and another smaller one in the evening at the Hotel Sherman.

Famous Flyers' Luncheon

An outstanding event was the Famous Flyers' Luncheon at which the Society was assisted by the Illinois Manufacturers' Association. About 800 listened to the brief talks and cheered the many aviation celebrities presented during the course of the luncheon. Dawson H. Skeen was toastmaster, and there were brief talks by C. B. Cole and Theodore R. Gerlach. The principal address was delivered by Edward S. Evans.

Technical Program

The following is a list of the papers delivered with the names of their authors:

Monday Morning, August 25

Construction and Operation of Gliders, Gilbert G. Budwig
Trend of Development in Aviation Gasoline, R. C. Alden

Monday Evening, August 25

Plywood in the Aircraft Industry, James R. Fitzpatrick
Stability and Controllability in Free Flight, Paul E. Hovgard
Future Aircraft Design Trends, Robert R. Osborn

Machine Shop Practice and Iron and Steel Divisions

CHICAGO, ILL., SEPTEMBER 22–26, 1930

More than 1400 members of the Society attended the Metal Congress held from September 22 to 26, 1930, at the Hotel Stevens, Chicago, Ill. The technical programs of the Machine-Shop Practice and Iron and Steel Divisions of the Society, The American Society of Steel Treaters, the American Institute of Mining and Metallurgical Engineers, and the American Welding Society brought out a total attendance for the Congress of nearly 6000. A Metal Industries Exhibit was held at the same time.

A.S.M.E. Dinner

Soviet Russia's program of industrial development in metal industries was the topic of the principal address by F. H. Wilcox at the joint dinner of the two Divisions and the Chicago Section on Wednesday evening, September 24. C. W. Bennett was toastmaster, and brief remarks were made by W. L. Abbott, W. W. Macon, W. W. Tangeman, Robert T. Kent, and Alex D. Bailey.

Technical Program

There was a generous turn-out of members of the Society augmented by many visiting members of other technical societies at the sessions of the Machine-Shop Practice and Iron and Steel Divisions. The following is a summary of the titles and authors of papers presented.

Tuesday Afternoon, September 23

Phenol Resinoid Molding Technique, Leon V. Quigley
Production of Plastic Telephone Parts, A. M. Lynn

Tuesday Evening, September 23

Flange Versus Foot-Mounted Motors, Herbert Chase
The Mechanical Design of Electric Motors as Regards Standardization and Interchangeability, J. L. Browne

Wednesday Morning, September 24

Fundamentals of Machine Polishing, Robert T. Kent
Repair of Worn Parts by Electrodeposition of Iron, T. P. Thomas

Wednesday Afternoon, September 24

Nitriding Analyses—Their Physical Properties and Adaptability, R. Sergeson and M. M. Clark
Case-Hardening with Ammonia Gas, Victor O. Homerberg and J. P. Walsted

Thursday Morning, September 25

Forces Acting on Rolled-Neck Bearings (A Report of the A.S.M.E. Research Committee on Heavy-Duty Anti-Friction Bearings), W. Trinks and John H. Hitchcock
General Design and Construction of Hot Saws for Cutting Heavy Structural Steel Sections, A. B. Pearson

Thursday Afternoon, September 25

The Manufacture of Large Weldless Forged-Steel Pressure Vessels, J. L. Cox
The Manufacture of Large Welded Pipe, Leon Cammen
Straightening of Steel by Rolling, J. Blair Sutton

Friday Morning, September 26

Recuperator Metallic Furnaces, G. D. Mantle
Continuous Reheating Furnaces for Rolling Mills, A. L. Culbertson

Friday Afternoon, September 26

Notes on the Production, Purification, and Uses of Blast-Furnace Gases, Wm. A. Haven and C. Brooks Thorne
Manual Semi-Automatic and Automatic Devices for the Protection Against Wind of Ore Bridges and Similar Structures, C. O. Burton

Materials Handling Division

CHICAGO, ILL., MARCH 5–7, 1930

"Organizing for Permanent Prosperity," which was the keynote of the week of March 3, 1930, in Chicago, proved to be an excellent drawing card for the Third National Meeting of the Materials Handling Division, held in that city in connection with the National Management Congress and under the auspices of the Chicago Section, from March 5 to 7. With a total registration of 800, all technical sessions were well attended and the plant-inspection trips proved to be very popular.

Technical Program

The titles and authors of papers are given in the following summary of the program.

Thursday Morning, March 6

Conveyor Handling Methods of the Chicago Daily News, M. W. Potts
Placing Wet Concrete With Belt Conveyors, E. L. Benson
Pneumatic Handling of Coal and Other Materials, H. H. Weiss

Thursday Evening, March 6

Shipment of Goods on Skid Platforms, F. J. Shepard, Jr.
The Industrial Tractor-Trailer Method of Materials Handling in the Meat-Packing Industry, A. D. Shanks
Industrial Plant Design and Operation as Effected by Transportation between Departments, Willard Brinton

Friday Morning, March 7

Material Handling in Production of Pork Products, A. W. De Vout
Recent Developments in Material Handling at the Western Electric Company's Merchandise Buildings at Kearny, New Jersey, C. K. Pevear

Friday Luncheon Meeting, March 7

Designing for Safety in Materials Handling, R. H. Hucke
Handling Materials in an Automatic Frame Plant, A. W. Redlin

Friday Evening, March 7

Effect of Modern Materials Handling on Materials Inventory and Scrap, E. J. Barney
Hidden Costs in Materials Handling, J. I. McCormick
What Does the Materials-Handling Equipment Manufacturer Need to Know to Make a Successful Installation? N. H. Preble

At Thursday's luncheon meeting, the question of standardization in the materials-handling field was discussed. It was decided that a report on the need for standardization would be presented at a future meeting.

Banquet

The banquet of the Materials Handling Division and the Management Congress was held at the Stevens Hotel on the evening of March 5. Dexter S. Kimball and Craig B. Hazlewood addressed the 400 in attendance. The toastmaster was Bernard J. Mullaney, president of the American Gas Association.

National Industrial Equipment Exposition

During the week there was held in the basement of the Hotel Stevens a National Industrial Equipment Exposition which was a combination exhibit of materials handling and management.

Oil and Gas Power Division

STATE COLLEGE, PA., JUNE 12–14, 1930

Gas turbines. Diesel-power costs, vibration, and nitriting were among the subjects covered in 17 papers presented at the Third National Meeting of the Oil and Gas Power Division held at Pennsylvania State College, from June 12 to 14, 1930, under the auspices of the Central Pennsylvania Section and the College. More than 300 were present at the technical sessions. The entertainment included a bridge party, dancing, a golf tournament, and a picnic. At the banquet Dean R. L. Sackett was toastmaster.

Technical Program

The following summary of the program gives the titles and authors of papers presented:

Thursday Morning, June 12

Address of Welcome, Ralph D. Hetzel
The Research of the National Advisory Committee for Aeronautics on Aircraft Diesel Engines, Carlton Kemper
Factors Affecting Nozzle Design in the Light of Recent Oil-Spray Experiments, P. H. Schweitzer
Pressure Variation in Common-Rail Fuel Injection System, Addison M. Rothrock

Thursday Afternoon, June 12

Progress Report on Research in Diesel Fuel-Oil Specifications, Wiley H. Butler
Report of Costs of Diesel Power, Franz Eder
Purification of Diesel-Engine Lubricating Oil, A. E. Flowers and M. A. Dietrich
The Lorensen Gas Turbine and Supercharger, C. A. Lorenzen

Friday Morning, June 13

Diesel Power-Plant Layout with Illustrations From Practice, E. W. Hammond
Joint Use of Diesel and Steam Engines to Balance Heat and Power, Edgar J. Kates
Economies of the Use of Electric Diesel Engines for Power Generation, T. A. Burdick

Saturday Morning, June 14

Nitride Hardening of Alloy Steels for Diesel-Engine Use, C. R. Alden
Some Phases of Light-Weight Diesel-Engine Design, P. B. Jackson
The Elimination of Torsional Vibration, Geo. J. Dashefsky

Saturday Afternoon, June 14

Natural-Gas Engines—Latest Gas-Engine Developments with Special Reference to Activities in California Oil Fields, V. L. Maleev
The Oil Engine in Aeronautics, E. E. Wilson
The Diesel-Engine Tractor and Excavator, C. G. A. Rosen
Gear Drives for Motorships, J. Barraja-Frauenfelder

Petroleum Division

TULSA, OKLA., OCTOBER 6–8, 1930

The first National Meeting of the Petroleum Division, held under the auspices of the Mid-Continent Section and the Petroleum Division in the auditorium of the Exposition grounds at Tulsa, from October 6 to 8, 1930, had an attendance of about 300.

Technical Program

The papers discussed pipe-line problems, pipe-line pumping stations, and refining. Each morning the speakers for that day gathered for a breakfast meeting at the Tulsa Club. The titles and authors of papers presented are given in the following summary:

Monday Morning, October 6

Purpose and Scope of the Petroleum Division, William G. Heltzel
Service Tests on Carbon Formation in Diesel Engines, E. H. Hillman
Lubrication of Power Cylinders of Diesel Engines and Causes of Cylinder Wear, J. M. McGregor and J. B. Harshman
Some Operating Data for Electrical Motor-Driven Reciprocating and Centrifugal Oil-Pipe-Line Pumps, W. H. Stueve

Monday Afternoon, October 6

Economic Design of Oil-Pipe-Line Transportation Systems, Oscar Wolf
Economics of Pumping Oil at Low Friction Losses, Fritz Karge
Report of Committee on Economic Analysis of Pipe-Line Pumping-Station Costs
Report of Committee on Fixed and Operating Charges for Diesel-Engine Pipe-Line Pump Stations, F. E. Waterfield

Tuesday Morning, October 7

Automatic Control of Pipe-Line Pumping Stations, J. B. Ford, J. B. McMahon, and T. D. Williamson
Temperature Observations for One Year on Streams of Petroleum Flowing in Mid-Continent Oil-Pipe Lines, Bert Martin and William G. Heltzel

Tuesday Afternoon, October 7

Effect of Hydrogen Sulphide on Wire Rope, Blaine B. Wescott and L. W. Vollmer
Use of Superheated Steam in Oil-Well Drilling, V. Weaver Smith
Report of Committee on Rotary-Drilling Equipment
Report of Committee on Unfired Pressure Vessels for Petroleum Industry

Wednesday Morning, October 8

Importance of Cracking Equipment in the Modern Refinery, Lyman C. Huff
Construction and Operation of Tube Stills for High Pressures and Temperatures, John Primrose
Stabilization and Absorption—Their Technical and Economic Positions in the Oil Industry, L. S. Gregory
Insulation of Cracking-Coil and Tube-Still Furnaces, E. V. Rinehart
Gasoline Recovery and Fractionation in the Refinery (*by title*), G. M. Jackson

Wednesday Afternoon, October 8

Improving Combustion Efficiency in Oil-Still Operation, Joseph R. Darnell
Reciprocating Hot-Oil Pumps, F. B. Applegate
Cottrell Process for Sulphuric-Acid Recovery, P. E. Landolt
Metallurgical Test Work Involved in Successful Adaptation of Alloy Steels to Industrial Purposes, R. L. Duff
The Flow of Steel at High Temperatures, F. H. Norton
Report of the A.S.M.E.-A.S.T.M. Joint Research Committee on the Effect of Temperature on the Properties of Metals, F. E. French

The International Petroleum Exposition held in Tulsa at the time of the meeting had many remarkable exhibits of production and refining equipment, and in addition there were some plant inspection trips on the program.

Printing Industries Division

NEW YORK, N. Y., APRIL 4, 1930

A very successful meeting of the Printing Industries Division was held in New York, April 4, 1930, under the auspices of the Metropolitan Section, in the auditorium of the Westinghouse Lighting Institute, Grand Central Palace. Leading printing-plant engineers described how plants are laid out and how production is conducted so that profitable operation will result.

Technical Sessions

There were two technical sessions. The papers presented and the authors are given in the following summary of the program:

Friday Afternoon, April 4

Engineering Research and the Publishing Industry, Samuel P. Weston
Printing-Plant Operation Without Alibis—Is It Possible? Hadar Ortman
Production Engineering in the Printing Plant, H. R. Lewis

Friday Evening, April 4

The Printing Engineer and Printing Profits, W. L. Churchill
The New Plant of the J. B. Lyon Company at Albany, Howard Chapman and Ernest A. Barvoets
The Printing Plant Engineer and His Profitable Work, O. J. Hutchinson

Textile Division

BOSTON, MASS., MAY 2, 1930

The Textile Division held a very successful National Meeting at Boston, Mass., on May 2, 1930, during the Textile Machinery Exposition. It was held under the auspices of the Boston Section and two technical papers were presented. They were:

Present Methods for Measuring the Physical Properties of Fabrics, W. F. Edwards
Theory and Practice of Textile Drying, B. R. Andrews

The afternoon was spent in a visit to the International Textile Exposition and in the evening a dinner was held at the Statler Hotel. The toastmaster was Henry M. Burke and the speakers Ray M. Hudson, who talked on "Progress and Stabilization in New England Textile Industries", and Ralph E. Flanders, who discussed "Engineering Approach to Continuous Prosperity for Industrial Plants."

Textile Division

GREENVILLE, S. C., OCTOBER 22, 1930

The Textile Division presented an interesting one-day program at Greenville, S. C., on October 22, 1930, in cooperation with the Greenville and Charlotte Local Sections, and during the Southern Textile Exposition.

Technical Session

The program opened with a session in the morning at the Poinsett Hotel. The papers presented and authors were as follows:

Humidification of Textile Plants, Edward D. Smith
The Treatment of Water for Bleaching and Dyeing, C. D. Blackwelder

The afternoon was spent by the visiting members and guests either in attendance at the Exposition or at a golf tournament which had been arranged by the Local Section.

Dinner Speakers

A dinner was held in the evening with David J. Kerr, chairman of the Greenville Section, presiding. The speakers included Wm. E. Mitchell, who gave an interesting talk on the development of public utilities in the South, and L. W. Wallace, who spoke on the subject of engineering in government. Short talks were given also by Henry M. Burke and James W. Cox, Jr. The dinner closed with a showing of the Japanese high-speed research film.

Wood Industries Division

NEW YORK, N. Y., OCTOBER 16-17, 1930

Splendid discussion and an unusually interesting exhibit were the high points of a National Meeting of the Wood Industries Division held at the Pennsylvania Hotel, New York, N. Y., on October 16 and 17, 1930, under the auspices of the Metropolitan Section.

At the dinner Friday evening there was lively discussion of "The Need of Forest-Products Engineers in the Wood-Working Industries," a paper presented by Nelson C. Brown and Raymond J. Hoyle. The toastmaster was Wilson Compton, who also contributed an interesting talk on the need of research and engineering development in the wood industries. On Thursday noon a luncheon was held, with Major Geo. P. Ahern as presiding officer, at which the topic of discussion was "Developments in Research in Tropical Woods and the Available Supply."

Technical Sessions

There were four technical sessions at which papers were presented. The authors and the titles of the papers follow:

Thursday Morning, October 16

Value of Wood Waste as Fuel, W. E. Biggs
Design of Fuel Feeders for Wood-Burning Furnaces, M. A. Hofft

Thursday Afternoon, October 16

The Science of Grading Timber for Strength, Leyden N. Erickson
Shrinkage in Wood, With Particular Emphasis on Longitudinal Shrinkage, Arthur Koehler
Curved and Bent Plywood, Thomas D. Perry

Thursday Evening, October 16

Opportunities for Utilization of Wood Waste in the Chemical Industries, B. B. Folger
Binders for Fibrous and Granular Woods, W. E. Emley
Developments in Stabilization of Painting Practice for Wood, F. L. Browne

Friday Afternoon, October 17

Abrasive Standards for Woodworking Operations, Elmer C. Schacht
Improvements in Steels for Wood Knives and Saws, Henry B. Allen

Plant Inspection Trips

On Friday morning, a number of inspection trips were made to factories in New Jersey and on Long Island where wood products were made. One of the unusual features of the meeting were the engineering exhibits. There were about fifteen of these which included samples of products made from wood waste, effects of seasoning of wood, mechanical tests, gluing of wood, samples of tropical woods, woodworking tools, and a historical exhibit.

Necrology

ARTHUR LEWIN ABRAHAMS

Arthur Lewin Abrahams, sales engineer for the Truscon Steel Company, Cleveland, Ohio, died on February 28, 1930, in Philadelphia, Pa. He was born in Lobsens, Germany, on January 23, 1888, the son of Morris and Natalia (Lewin) Abrahams. He received his education at the Central Manual Training High School, Drexel Institute, and the University of Pennsylvania, Philadelphia, Pa. He began his engineering work in 1904 as part-time apprentice toolmaker in a collar button works. In 1906 he became draftsman for the Warren Webster Company, manufacturers of steam specialties; in 1907 draftsman at the Baldwin Locomotive Works, Camden, N. J., working on electric mining locomotives; and in 1908 draftsman and subsequently assistant superintendent of the Bernstein Mfg. Co. in Philadelphia, for whom he designed and built sterilizers and operating tables. For ten years, beginning in 1910, he served successively as draftsman, chief estimator, and sales engineer for the Hale & Kilburn Corp., Philadelphia. During the early days of this connection he assisted in the design of pressed steel equipment for railroads, automobiles, and buildings. Later he concentrated on the development of the business and the capacity of the plant. In 1920 he engaged in export business, handling general mechanical products, and in 1924 became factory manager for the Kny-Scheerer Corporation of America, New York, N. Y., manufacturing a complete line of highly specialized hospital supplies and equipment. His connection with the Truscon Steel Company began in 1925 as sales engineer and eastern representative, located in New York. He transferred to Cleveland in 1930.

Mr. Abrahams joined the A.S.M.E. as an associate member in 1925. Fraternal organizations of which he was a member included the Elks and Masons.

Surviving Mr. Abrahams are his widow, Johanna Cohen, whom he married in 1911, and two children, Hermine and Naomi.

HENRY C. ACKERMAN

Henry C. Ackerman, mechanical engineer for the Municipal Water & Light Dept., Kansas City, Kan., died in that city on June 6, 1930, of pneumonia. He was born there on June 23, 1889, the son of Charles H. and Ida B. (James) Ackerman. His education was received at the Manual Training School of Kansas City and at the University of Kansas, at Lawrence, where he received the degree of B.S. in Mechanical Engineering in 1914. His early professional experience was secured as station attendant and field constructor for the Kansas Natural Gas Company, Independence, Kans., and as draftsman and designer in the bridge and mechanical departments of the Kansas City Terminal Railway Company.

Following his graduation Mr. Ackerman was employed in the mechanical department of the Kansas City Electric Light Company for a year, and in 1916 became maintenance engineer for the Hercules Powder Company, at Kenvil and Parlin, N. J., where he designed and installed a heavy hydraulic pressing and pumping system. In 1918 he entered the service of the Gorham Mfg. Co., Providence, R. I., as mechanical superintendent of the shell loading plant. A year later he became master mechanic of the By-Product Coke Plant of the Colorado Fuel & Iron Co., Pueblo, Colo. During the latter part of 1920 he was inspecting engineer on the construction of a power house for the Sinclair Refining Company, Kansas City, after which he spent two years as a member of the firm of Angevine & Ackerman, manufacturers' agents for power-plant equipment, Kansas City. In 1922 he became superintendent of construction of a new 800-kw. power plant at the State Penitentiary of Kansas at Lansing, where his work included the layout of a heating tunnel and the installation of a new electric distribution system. He had been with the Kansas City water and light department since 1923.

Mr. Ackerman became a junior member of the A.S.M.E. in 1916 and an associate member in 1923. He married Marianna Chase in 1923, and she, together with three children, Thomas James, Alice Marea, and Barbara Ann, survive him.

KILBURN ELIE ADAMS

Kilburn Elie Adams, superintendent of the Employment Department of the Edison Electric Illuminating Company of Boston since 1919, died on December 24, 1930, at his home at Waban, Mass. Mr. Adams was born at Cambridge, Mass., on January 18, 1882, the son of Kilburn and Cecelia Aurelia (La Pierre) Adams. He attended the Cambridge Latin School, Harvard College, where he received the degree of A.B. in 1902, and Harvard University (Lawrence Scientific School), where he was given the degree of S.B. in 1903. He also finished a course in Public Utility Management at the Harvard Graduate School of Business Administration in 1926.

Mr. Adams had a very broad engineering experience which began in 1903 when he had charge of the surveying for the Harvard Stadium. He spent a year as draftsman of pipe fittings and power-plant layouts for the Walworth Mfg. Co., Boston, Mass., and a little later was engaged by that company to make drawings for the 59th Street power station of the Interborough Rapid Transit Company in New York. He also had experience in building pumps and pumping engines for the Geo. F. Blake Mfg. Co., Cambridge, in 1904. In 1905 he became mechanical engineer for Sayles Bleacheries, Saylesville, R. I. From 1905 to 1907 he also assisted E. D. Leavitt, consulting engineer, Cambridge, Mass., in making computations and drawings for a stamp mill of the Calumet & Hecla Mining Co.; was assistant in charge of the engineering experimental laboratories at Harvard; and helped H. L. Gantt with the installation of the Taylor System at Stokes & Smith Co., Philadelphia, Pa. In 1907 he became connected with the firm of Wm. Underwood Co., Boston, Mass., as mechanical engineer and assistant manager of five canning factories in Maine and Massachusetts. For four years he was with the Boston and Albany Railroad as mechanical engineer in charge of design and construction work, which included the terminal at East Boston, passenger stations at Worcester and Pittsfield, Mass., and alternating-current and direct-current power plants, pumping and coaling plants, and fire-protection, power and light, and heating and ventilating systems. He also had charge of the design and construction of high-tension power-transmission lines owned by power and light companies where these crossed the railroad right of way. In 1913 he became head of the Incandescent Lamp Division of the Edison Electric Illuminating Company, Boston, Mass., where he had charge of the incandescent lamp work connected with the commercial and residential lighting in that territory.

Mr. Adams became a junior member of the A.S.M.E. in 1908 and a member in 1917. He also belonged to the American Management Association, Harvard Engineering Society, National Electric Light Association, and Associated Industries of Massachusetts. He was a member of the Committee on Employment of Rehabilitated Veterans for the Boston Chamber of Commerce, and was president of the Edison Employees Club in 1919–1920. He was much interested in athletics. His religious faith was Unitarian.

He married Elizabeth Florence Gilbert in 1908, and she, together with three children, Kilburn Elie, Jr., Gilbert Crocker, and Elizabeth Cecilia Adams, survive him.

DANIEL ADAMSON

Daniel Adamson, of Longlands, Hyde, Cheshire, England, head of the firm of Messrs. Joseph Adamson & Co., boiler makers and engineers, at that place, died on October 11, 1930, of heart failure following an operation.

Dr. Adamson came of a family conspicuous in engineering research and development in the North of England for more than a century. He was a grand-nephew of the pioneer of the Manchester Ship Canal and not only followed the family traditions, but explored new fields such as the electric overhead traveling crane and the harnessing of waste heat from boilers. He was considered an authority on spur gearing and won the Hawksley gold medal for a paper on that subject presented before the Institution of Mechanical Engineers in 1916. In 1929, during his year as president of the Institution of Mechanical Engineers, he was invested with the honorary degree of Doctor of Science by the University of Manchester in recognition of his services to engineering and engineering research.

Born at Newton Moor, Hyde, England, on August 26, 1869, the son of Joseph and Hannah (Platt) Adamson, his education was received in a private school in Hyde and at the College of Technology, Manchester. He served an apprenticeship with and subsequently worked as supervisor for Messrs. Scott & Hodgson, Ltd., Guide Bridge, near Manchester. He entered his father's company as foreman in 1889 and served in that capacity and subsequently as works manager until 1902, when he was made a partner. He became sole proprietor in 1925.

In 1894, Messrs. Joseph Adamson & Co. built the first electric three-motor overhead traveling crane, after Dr. Adamson had visited the United States to investigate its possibilities. Later he visited

the Continent to investigate a process in connection with boiler making, but owing to local conditions was unable to adopt it. About this time, Dr. Adamson was active on the Committee of the Manchester Association of Engineers, carrying out experiments showing the possibilities of high-speed steels which he had first seen at work in the Paris Exhibition of 1900. In 1912 he read a paper on conditions affecting the durability of wire ropes before the Institution of Mechanical Engineers. Among his other technical papers was one on the "Design and Construction of Electric Cranes" for which he was awarded the Constantine gold medal by the Manchester Association of Engineers in 1926. He contributed many other papers to the technical press and to engineering societies on subjects connected with power transmission, wire ropes, spur gearing, cranes, and engineering economics.

Dr. Adamson had been a member of the A.S.M.E. since 1901. Prior to his presidency of the Institution of Mechanical Engineers he had served on its council for thirteen years and been vice-president for six years. He was a member of the Institution of Civil Engineers and past-chairman of its Manchester Association, a member of the Institution of Electrical Engineers, and a life member of the Société des Ingénieurs Civils de France and of the American Institute of Electrical Engineers. Other engineering societies to which he belonged included the Association of Iron and Steel Electrical Engineers, Manchester Association of Engineers, of which he was past-president, the American Institute of Weights and Measures, the American Welding Society, the North East Coast Institution of Engineers and Shipbuilders, The Newcomen Society, the Literary and Philosophical Society of Manchester, and the Boiler Manufacturers' Association of Great Britain, of which he was chairman. He was an original member of the Engineers' Club of Manchester and served as its president in 1919–1921.

Socially Dr. Adamson was a staunch churchman and did a great deal of work on behalf of churches in his district. He was a trustee of the Hyde Lads' Club. As a member of the Federation of British Industries Delegates he visited the United States in 1927 on a tour of inspection of the State of Virginia.

He married Alice Maud Ryder in 1895 and is survived by her and two children, George Ryder and Joseph Adamson, who will carry on the business.

GEORGE VICTOR AHARA

George Victor Ahara, consulting engineer for The Canadian Fairbanks-Morse Co., Ltd., died at his residence in Toronto, Canada, of heart failure, on August 25, 1930. He was born at Evansville, Wis., on October 21, 1870, his parents being Hugh and Mary J. (Leighton) Ahara. He received his education at the Evansville Seminary and at the University of Wisconsin, by which he was given the degree of B.S. in Mechanical Engineering in 1895.

Mr. Ahara's engineering experience began in 1892 in the machine shop of the Berlin Machine Works, Beloit, Wis. Following his graduation he entered the testing department for internal-combustion engines and was subsequently assistant superintendent of the department for The Fairbanks-Morse Mfg. Co., at Beloit. In 1906 he became mechanical engineer of The Canadian Fairbanks-Morse Company at Toronto, and had charge of drawings and designs for internal-combustion engines for marine, portable, stationary, and tractor service, pumps, railway standpipes, and transmission machinery. He held patents on a number of improvements in gasoline engine carburetors. He became consulting engineer for the company in 1914.

His membership in the A.S.M.E. began in 1913. He was a member of the Methodist Episcopal Church and the Masonic fraternity. In 1898 he married Evelyn Ainsworth, who with three children, Edward Victor, Leroy Dale, and Robert Leighton Ahara, survive him.

WILLIAM HOWARD ARNOLD

After a few month's illness, William Howard Arnold died of blood poisoning at Hollywood, Calif., on January 4, 1930. He was born in Salt Lake City, Utah, on April 10, 1905, the son of Frederick E. Arnold. His education was received in the East High School at Salt Lake City, and at the University of Michigan, where he was given the degree of B.S. in Mechanical Engineering in 1926. After graduation he became sales engineer for Charles C. Moore & Co. and for a time was at the San Francisco office, but later was transferred to the Los Angeles office. He was a member of the Tau Beta Pi and Beta Theta Pi fraternities, and unmarried. He became a junior member of the A.S.M.E. in 1927.

Mr. Arnold is survived by his father, a brother, and a sister.

BENJAMIN ROBERT ATKINSON

Benjamin Robert Atkinson, chief engineer of the Morrison Machine Company, Paterson, N. J., died on April 11, 1930, following an operation for appendicitis. He was born in Paterson, N. J., on May 18, 1900, the son of Benjamin and Isabella (MacCandles) Atkinson. His education was received in the public schools of Paterson and at the Stevens Institute of Technology where he was given the degree of M.E. in 1921.

Mr. Atkinson's professional experience began in 1921 as traffic engineer with the Western Union Telephone Company, New York, N. Y. In 1922 he joined the General Electric Company at Harrison, N. J., as engineer in charge of production and development of ballast lamps. He became engineer for the Morrison Machine Company, manufacturers of textile machinery, in 1923 and was appointed chief engineer in 1928.

Mr. Atkinson became a junior member of the A.S.M.E. in 1925. He was very active in the work of the Wesley Methodist Episcopal Church at Paterson. He was president of the Paterson District of the Epworth League and a member of the Advisory Committee for the local troop of Boy Scouts. He married Eleanor L. Leather in 1928 and is survived by her.

CLARENCE MORSE BARBER

Clarence Morse Barber, chief engineer of the Michigan Copper & Brass Co., Detroit, Mich., died at his home on July 30, 1930. He was born at Berea, Ohio, on October 5, 1852, the son of Gershorn Morse and Huldah Lavinia (Seeley) Barber. He attended the Cleveland public schools and Rensselaer Polytechnic Institute, where he received the degree of Civil Engineer in 1878.

His professional experience began in 1878 as a draftsman for the King Iron Bridge Company, Cleveland, Ohio. From 1880 to 1885 he was chief engineer of the Cleveland, Lorrain & Wheeling Ry., and for the next two years engaged in private engineering practice at Cleveland. He then spent two years as superintendent of the Foxhall Tuning & Mining Co. and the Casino Mining Company in Colorado, and was superintendent and engineer for the National Carbon Company, Cleveland, from 1889 to 1895. From then until 1912 he served successively as engineer for the Brown Hoisting & Conveying Machinery Co., as constructing engineer of the Semet-Solvay Company, and as engineer for Smith, Hinchman & Grylls, architects and engineers, Detroit. During the next five years he carried on private practice in civil engineering. He had been connected with the Michigan Copper and Brass Co. for a number of years.

Mr. Barber developed and patented a machine for automatic electroplating of electric light carbons. Among his technical articles was one on "Fuel Briquetting in America," and he read a paper before the American Society of Civil Engineers at the World's Fair in Chicago in 1893, on "Carbon and Its Uses in Electrical Engineering." He became a member of the A.S.M.E. in 1904. He was also secretary and vice-president of the Cleveland Engineering Society, president of the Rensselaer Polytechnic Alumni of Detroit, and a member of the Detroit Engineering Society and the Ohio Society of Detroit. He belonged to the Methodist Church and was interested particularly in nature study, astronomy, and photography. He gave a great deal of his time to young men, helping many in connection with their college work. In 1882 he married Minnie Kate Brown, who died in 1905. One daughter, Grace L. Barber, of Detroit, Mich., survives him.

NEIL FRANKLIN BEESON

Following an automobile accident, Neil Franklin Beeson, assistant in mechanical engineering at the University of California, died on January 29, 1930. He was born at Albion, Iowa, on July 15, 1900, his parents being George Bernard and Lillian A. Beeson. His education was received at the High School at Marshalltown, Iowa, at the Iowa State College, and at the University of California, where he received the degree of B.S. in 1927.

Mr. Beeson began his professional work while still in college, during vacations serving as machine operator for the C. A. Dunham Co. and the Fisher Governor Company, at Marshalltown. He also worked in the machine shops of the Minneapolis & St. Louis R.R., and on automobile repair work, and from 1923 to 1925 he was a special apprentice on machine-shop work, layout and drafting, air-brake repair work, and car shop experience, in the shops of the Chicago & Alton R. R. at Bloomington, Ill. In 1927 he became teaching fellow, and in 1929 assistant in mechanical engineering at the University of California. He was a Christian Scientist in religion and was interested particularly in music, playing both the clarinet and piano, and in athletics. He was unmarried.

HANS C. BEHR

Hans C. Behr, retired, died at the age of 75, on March 29, 1930, at White Plains, N. Y., from injuries received when he was struck by an automobile earlier in the year. He was born in San Francisco, Calif., on February 9, 1855, his parents being Hans Charles and Agnes (Omilsky) Behr. He received his education in the public and Jesuit schools of San Francisco, the Gymnasium at Cöthen, Anhalt, Germany, and at St. Ignatius College, San Francisco.

His professional experience began as an apprentice and draftsman in the Union Iron Works, San Francisco, for which he later went to the Comstock mines to act as assistant to the chief engineer. He also served as assistant to the chief engineer, W. H. Patton, at Virginia City, Mo., in connection with design and erection of winding machinery, and as assistant to W. R. Eckert of San Francisco in the design and laying out of metallurgical plants. In 1899, after some private practice as a consulting engineer, he went to Johannesburg as consulting metallurgical engineer for the Consolidated Goldfields of South Africa. He took up consulting practice in New York again in 1912.

Mr. Behr had many American patents pertaining to percussion apparatus, pneumatic stamping, ore feeders, and mining equipment. He also had patents on valve gears and machines and equipment for separating liquids from solids. British patents included improvements in pneumatic percussion apparatus, pneumatic ore stamps, hammers, and the like. He contributed many papers to technical societies on mining methods and equipment, for several of which he was awarded gold medals. He was a life member of the A.S.M.E., which he joined in 1891, and of the South African Institution of Engineers, a member of the Institution of Civil Engineers, the Institution of Mechanical Engineers, and the Institution of Mining and Metallurgical Engineers in England, and a fellow of the Royal Society of South Africa. He had served as a member of the Patents Committee of the Transvaal Chamber of Mines, and of the Rand Mines Trials Committee, organized to experiment with new devices of interest to the mining industry. A son, Hermann Behr, of Watertown, Mass., survives him.

JOE A. BERGIN

As a result of a gas explosion during an inspection of new workings and methods of mining and preparation of coal, at Millfield, Ohio, Joe A. Bergin died on November 5, 1930. He was superintendent of The Ohio Power Company at the Philo Plant, Philo, Ohio.

Mr. Bergin was born at Hartland, Mich., on July 29, 1886, his parents being Frank M. and Mary (Rigney) Bergin. He received a high-school education. In 1914 he became operating engineer at the Delray Plant of The Detroit Edison Company, where he remained until 1920 when he was transferred to the Construction Engineering Bureau of the company, as a critic on the design of the Marysville steam electric generating plant. For three years, from 1921 to 1924, he was assistant manager of the Beech Bottom Power Company, during which period he served as combustion engineer and assistant manager in connection with the operation of the Windsor steam electric generating station, and a 60,000-kw. extension. He had been superintendent of The Ohio Power Company since 1924.

During the World War Mr. Bergin was in charge of steam-making equipment for the du Pont munitions operations near Nashville, Tenn.

He became a member of the A.S.M.E. in 1925 and was actively connected with the work of the Prime Movers Committee of the National Electric Light Association, having held the chairmanship of the Boilers, Superheaters, and Economizers Sections, and been a member of other sections. His club membership included the Zanesville Golf Club, Zane Club, Knights of Columbus, and Elks. He was a Roman Catholic in faith, a member of the St. Thomas Church in Zanesville, and was particularly interested in outdoor sports. He married Estelle M. Hogan in 1912 and she, together with one son, Robert Bergin, survive him.

WILLIAM C. BERRY

William C. Berry, designer and vice-president of the Berry Machinery & Supply Co., San Jose, Calif., died on July 24, 1930, in that city. He was born in Philadelphia, Pa., on March 12, 1882, the son of William C. and Lydia A. (Leach) Berry. He received his education at the Central Manual Training School, Philadelphia.

Mr. Berry entered the employ of the Falkenau-Sinclair Machine Company in Philadelphia, in 1900, and later worked in the crane and injector department of Wm. Sellers & Co. In 1906 he became connected with the Joshua Hendy Iron Works, San Francisco and Sunnyvale, Calif., in the design of waterwheels, ball and tube mills, stamp mills, and layouts for mill buildings, for a number of years being in charge of drafting and estimating. He was next associated, in 1919-1920, with J. H. McCullough, San Jose, Calif., working on the design of tractors and airplane engines. In 1920 he engaged in the design of pottery machinery for the Homer Knowles Pottery, Santa Clara, and in the following year designed a plant for Stanley Hiller, Inc., San Jose.

He was first connected with the Berry Machinery & Supply Co. in 1922, working on pumps and brine circulators for ice plants. In 1923 he designed tamping machinery and concrete molds for the Thermotite Construction Company, San Jose; in 1924 worked on screw presses for Stanley Hillier, Inc.; and in 1926 was engaged by the Standard Gas Engine Company of Oakland, on tractor design, and by Sanderson & Porter, San Francisco, in connection with fish meal and oil plant layouts.

He became an associate member of the A.S.M.E. in 1927, was a thirty-second degree Mason, and religiously was affiliated with the Rosicrucians. A son, William C. Berry, Jr., survives him.

ALEXANDER LESLIE BLACK

Alexander Leslie Black, vice-president of Ford, Bacon & Davis, Inc., died in San Francisco, Calif., on March 3, 1930. He was born in New Orleans, La., in January, 1871, and attended private preparatory schools in New Orleans and New York. He was graduated from the School of Mines, Columbia College, in 1890, and then engaged in mining work in the West and in Mexico for three years, subsequently acting as assistant engineer on the topographical survey of New Orleans. In 1894, Mr. Black took charge of the reconstruction for electric operation of the St. Charles Street Railroad Company in New Orleans and remained with that company, supervising operation and construction for this and other local companies, until 1901, when the New Orleans properties were consolidated. He then became engineer for the New Orleans Railway & Light Co. and its predecessors controlling the New Orleans Street Railways & Lighting Companies.

Mr. Black became identified with the firm of Ford, Bacon & Davis, Inc., in 1910. His first work was as engineer in charge of southern properties, supervising the reconstruction, maintenance, and operation of street railway, electric light and power, and water and gas properties. These activities engaged Mr. Black's time until 1914, when he became chief engineer of design and construction of public cotton warehouses and terminals in New Orleans. Two years later he was appointed chief engineer on the design and construction of the New Orleans Public Grain Elevator. The eight years following this engagement, which consumed only one year, were occupied with valuation and rate negotiations for various street railways and power companies.

In 1924 and 1925 Mr. Black was vice-president in charge of the Market Street Railway, San Francisco, and for two years following was chief engineer of the New Orleans Pontchartrain Bridge. Failing health caused Mr. Black to curtail activities during the three years previous to his death, and he alternated between the Corporation's New York and Birmingham offices. His last assignment was as consultant during the construction of the transportation system of the Southern Natural Gas Company.

Mr. Black became a member of the A.S.M.E. in 1915, and belonged also to the American Society of Civil Engineers, American Institute of Electrical Engineers, American Association of Engineers, and the Louisiana Engineering Society. He is survived by his widow, the former Virginia Bullitt Grant, and two sons, William Grant and Alexander Leslie Black.

HAROLD MICHAEL BRADY

Harold Michael Brady, assistant engineer of the General Petroleum Corporation, Los Angeles, Calif., died at his home in Los Angeles on January 25, 1930. He was born in Marion, Ind., on September 23, 1900, his parents being Alfred Tennyson and Jessie Anna (Barley) Brady. He received his education at the California Institute of Technology, obtaining the degree of B.S. in Mechanical Engineering in 1922. He began work with the General Petroleum Corporation of California as draftsman and later was designer and assistant engineer of design.

Mr. Brady became a junior member of the Society in 1922, and he also was a Mason. He was a Presbyterian in faith, and he was particularly interested in engineering and mathematical subjects, and in ancient and religious history. He was unmarried.

WILLIAM HENRY BRISTOL

William Henry Bristol, inventor of the Bristol phone and numerous recording instruments and president of the Bristol Company of Waterbury, Conn., died on June 18, 1930, in the New Haven Hos-

pital. He had been suffering for several months from a blood clot in the region of the heart.

Professor Bristol was a pioneer in the manufacture of recording instruments in America. In 1915 he conceived the idea of recording simultaneously sound and action. The invention and production of the Bristol phone, which synchronizes both in motion pictures, followed. To perfect this instrument he spent nearly a million dollars. A fully equipped motion picture laboratory and studio in Waterbury were constructed for this purpose. Other inventions included steel belt lacing and instruments for measuring pressure, temperature, electricity, speed, and time.

Professor Bristol was born on July 5, 1859, in Waterbury, the son of Benjamin Hiel and Pauline (Phelps) Bristol. He was graduated from Stevens Institute of Technology, at Hoboken, N. J., in 1884 with an M.E. degree. While a student there he organized and taught in the manual training department of the Workingman's School in New York. After his graduation he was appointed instructor and later, a professor of mathematics, at Stevens, where he taught until 1906.

He founded the Bristol Company in 1899 to manufacture and market his inventions. He held many medals awarded him at various expositions for his inventions. Among these were the John Scott Legacy medal, which he received from the Franklin Institute at Philadelphia in 1890, and one awarded at the sesquicentennial at Philadelphia in 1926; a medal and diploma at the Chicago Exposition in 1893, a silver medal at the Paris Exposition in 1900, a gold medal at the St. Louis Exposition in 1904, and a grand prize at the Panama Pacific International Exposition in 1915.

He was a member of numerous societies, including The American Society of Mechanical Engineers, which he joined in 1890, Society of Electro-Chemical Engineers, Society of Motion Picture Engineers, and American Institute of Electrical Engineers. He also was a fellow of the American Association for the Advancement of Science.

Professor Bristol's first wife was Miss J. Louise Wright, of New York, who died in 1888. His second wife was Miss Elise H. Myer of Jersey City, whom he married in 1899. He is survived by two brothers, Bennett G. and Edgar H. Bristol of Foxboro, Mass., and one sister, Mrs. Bertha Bristol Tracy of Wellesley, Mass.

WILLIAM MILTON BROCK

William Milton Brock died at his home in Paterson, N. J., on July 4, 1930. He was born in Brooklyn, N. Y., on November 3, 1856, the son of Samuel Gowan and Elizabeth Lamb (Docherty) Brock. His father being in the Union Army during the Civil War, Mr. Brock started work at an early age as slate picker in a coal breaker in Pennsylvania, where the family then resided. In 1886 the family returned to Brooklyn, where he attended public school for a time, sold newspapers, worked in a jewelry store, and was a blacksmith's helper. In 1869 the family removed to Shamokin, Pa. After again working for a time in a coal breaker he secured employment as a messenger for the Mineral Railroad & Mining Co., carrying reports between their offices and those of the Northern Central Railway Company.

About this time Mr. Brock became interested in electricity, and devoted the major part of his spare time to the study of telegraphy, mathematics, and mechanical drawing.

In 1873 the Mineral Railroad & Mining Co. connected its several collieries by telegraph with its own general office and those of the Northern Central Railway Company, and Mr. Brock was appointed operator at the Cameron office. In 1879 he accepted a position as car record clerk with the Northern Central Railway Company. During these years he carried on experimental work in telegraphy and telephony. He constructed a set of telephone instruments which he operated over an 18-mile telegraph line between Shamokin and Sunbury, Pa. He also constructed one of Mr. Edison's latest tin-foil phonographs during this period.

In 1879 he was appointed manager of the Shamokin Division of the Central Pennsylvania Telephone & Supply Co., a newly organized concern with headquarters at Williamsport, Pa., and while there invented in 1882 a central office telephone switchboard system for which he secured letters patent in 1883. After installing exchanges in Shamokin, Sunbury, and Mt. Carmel, all connected by trunk lines, Mr. Brock resigned in 1883 to accept a position with the newly organized Edison Electric Illuminating Company of Shamokin, to assist in the installation of equipment.

In 1886 Mr. Brock accepted the management of the Edison Electric Illuminating Company of Lawrence, Mass., one of the first installations of the Edison municipal system of series street lighting, and of some of the early Sprague motors. He resigned three years later to become secretary and general manager of the Edison Electric Illuminating Company of Paterson, N. J., where he had the acute competition of the Paterson Electric Company, which was furnishing the city with Thomson-Houston arc service and a three-wire commercial incandescent system using Sawyer-Man lamps.

In April, 1890, the two companies were merged, and by 1894 the current demand had so increased as to necessitate the erection of a new and up-to-date plant. Mr. Brock contributed many valuable ideas to the design and equipment of the new plant, which was put in commercial operation in 1896. From then until his retirement in 1926 Mr. Brock occupied the position of division superintendent of the Public Service Gas & Electric Corp. of New Jersey, with headquarters at Paterson.

He became a member of the A.S.M.E. in 1894 and was also a member of Edison Pioneers, of which organization he was elected a vice-president in 1926. For many years he was a member of the Hamilton Club. He belonged to the Church of the Messiah (Presbyterian) in Paterson. He was particularly interested in Japanese carvings and pottery, of which he had made a considerable collection.

In 1885 he married Florence Vincent Wilson, who, together with three daughters, Mrs. Elizabeth Rogers, Mrs. Mildred Simonds, and Mrs. Florence Huber, survive him.

VICTOR H. CARPLES

Victor H. Carples, secretary and treasurer of the L. J. Wing Mfg. Co., New York, N. Y., died on September 3, 1930. He was born in New York on January 7, 1886, the son of Emanuel and Anna (Brown) Carples. He attended the College of the City of New York, where he received the degree of A.B. in 1904, and Columbia University, securing the degree of E.E. there in 1910.

After graduation Mr. Carples became associated with P. R. Moses and the Engineering Supervision Company in New York, where he inspected and tested isolated power plants and was engaged in the laying out of new plants. In 1911 he joined the L. J. Wing Mfg. Co. His work involved layouts and tests of boiler plants with special reference to forced-draft systems. He supervised considerable research work on fans and blowers. He became secretary and treasurer of the company in 1917. Mr. Carples held a joint patent with A. E. Seelig on an air-blowing device. He joined the A.S.M.E. as an associate member in 1921, and became a member in 1923. He was greatly interested in music and was an able pianist. One daughter, Ann Barbara, survives him.

WALTER LEE CHENEY

Walter Lee Cheney, retired, died on August 15, 1930, at his home in Meriden, Conn. He was born at Greenfield, Mass., on October 7, 1854, the son of Ebenezer and Rowena (Hastings) Cheney. After receiving a high school education, he began his professional work as an apprentice machinist with the Pratt & Whitney Co., Hartford, Conn. He worked for four years in the shops and followed this with five years of drafting room experience. After being connected for a time with the Springfield Machine Tool Company, Springfield, Ohio, and with Warner & Swasey Co., Cleveland, Ohio, he became associate editor of *Machinery*. Under the pen name of Charles W. Lee he contributed articles to this and other technical publications. Following this connection he was engaged successively as foreman for the New Home Sewing Machine Company, Orange, Mass., assistant superintendent for the Hancock Inspirator Company, Boston, Mass., and superintendent for the June Sewing Machine Co., Chicago, Ill., and the American Sewing Machine Company, Philadelphia, Pa. His subsequent positions included that of mechanical engineer for the Westinghouse Electric & Manufacturing Co,. Newark, N. J., foreman for Moses G. Crane & Co., Boston, Mass., secretary of the Meriden Machine Tool Company, Meriden, Conn., salesman for the Walter H. Foster Co., New York, and for the Potter & Johnson Co., Pawtucket, R. I., and for more than twenty-five years, sales engineer for the Lucas Machine Tool Company, Cleveland, Ohio.

He became a member of the A.S.M.E. in 1883 and also was a member of the American Association for the Advancement of Science, the National Geographic Society, and the Machinery Club of New York. In 1879 he married Elizabeth Adams Whitney. The following children survive him: Rowena, Amos E., and William L. Cheney, and Mrs. Fred R. Collington.

CHARLES CLIFFORD COCHRAN

Charles Clifford Cochran, whose death occurred on January 28, 1930, had been associate professor of mechanical engineering at the Pennsylvania State College since 1920, and in charge of the mechanical laboratory under Professor Wood since 1922. He was born in Denver, Colorado, on November 26, 1870, his parents being Shelby and Susan (Ralston) Cochran. He received his education in the

Denver schools and at the University of Colorado, where he was given the degree of B.S. in Mechanical Engineering in 1906.

Prior to his graduation, Mr. Cochran served an apprenticeship in the machine shops of several railways in the Central West, and for two years he was acting foreman of the Denver and Rio Grande Southern Railroad. After graduation he became assistant professor of mechanical drawing at the University of Kansas, and for three years was engaged in selling educational courses for the Emerson Institute of Indiana and the La Salle Extension University, Chicago.

Mr. Cochran had several patents relating to motion reduction and to a mercury barometer with electric attachment for setting the scale by ear instead of by eye. He was the author of a thesis on the Proximate Analysis and Heating Value of Colorado Coals. He joined the A.S.M.E. as a member in 1922. He also belonged to the University Club of State College and the Tau Beta Pi fraternity. His first wife, Lucy Ballinger, died in 1916. Mary E. (Hoy) Cochran, whom he married in 1927, survives him.

GUY BAIN COLLIER

Guy Bain Collier, president and treasurer of the Collier Manufacturing Corporation, and a well-known consulting and designing engineer, died at his home in New York, on June 15, 1930. He was born in Kinderhook, N. Y., on July 12, 1877, the son of Gerrit Sager and Lydia (Bain) Collier. He attended Union College, Schenectady, N. Y., and subsequently Harvard University, where he was given the degree of S.B. in 1901 and an A.M. two years later.

For eight years beginning in 1901 Mr. Collier tutored in mathematics, engineering and physics, and astronomy at Harvard and the Massachusetts Institute of Technology. In 1906 he entered partnership with N. B. Wales, Boston, Mass., and was engaged in engineering and development work. Five years later he began a private practice in development work relating to dynamic heating systems, steam turbines, gas engines, hydrocarbon motors, valve mechanisms, and mechanical devices.

Mr. Collier joined the U. S. Shipping Board, Supply Division, District A, Boston, in 1918 as production expediter under H. L. Bond, supervising Shipping Board work at several plants. He served as senior examiner in the New York office of the Shipping Board in 1919.

He returned to private work as consulting and designing engineer with the Collier Motor Patents Corporation in 1919. His clients included the Eagle Picher Lead Company, Newark, N. J.; C. W. Short, Jr., architect of New York, for whom he designed trusses and structural steel; and the Sharples Specialty Company, of New York and Philadelphia, for which he designed two oil-refinery dewaxing plants. He also designed a 176-ton steel coal bunker, suspension type, for the power house of the Essex County Hall of Records, Newark, N. J., and the mezzanine floor and stairs of the Continental Bank in New York.

Mr. Collier held a number of patents relating to internal-combustion motors, reciprocating engines, aeroplane propellers, carbureters, and gas-lighting apparatus. Patents were pending on a gas-cooled valve, gas switch, a water-cooled valve engine with detachable cylinder head, and other developments in valve engines.

Mr. Collier became a member of the A.S.M.E. in 1922. Among his contributions to its publications was a paper on the Analysis of Strains and Stresses in a Wristpin, presented at the 1927 Annual Meeting. He was also a member of the Harvard Engineering Society, and he belonged to the Dutch Reformed Church. In 1924 he married Elvira Brewster, who survives him.

JACOB DOLSON COX

Jacob Dolson Cox, chairman of the Board of Directors of the Cleveland Twist Drill Company, died at Pasadena, Calif., on February 23, 1930. He was born in Warren, Ohio, on May 15, 1852, the son of Major-General Jacob Dolson and Helen Clarissa (Finney) Cox. After a common school education he entered the service of the Cleveland Iron Company in 1869 and successively held the positions of ore weigher, machinist, roll-turner, puddler's helper, and roller's assistant. He also worked with J. F. Holloway on marine engines at the Cuyahoga Steam Furnace Company. In 1876 he associated himself with C. C. Newton in the firm of Newton & Cox, manufacturing twist drills. His firm was located first at Dunkirk, N. Y., and then at Cleveland, Ohio. In 1879 Mr. Cox bought out Mr. Newton and continued the company as J. D. Cox until 1880, when he sold an interest to F. F. Prentiss, and the firm became Cox and Prentiss. This was incorporated in 1904 as the Cleveland Twist Drill Company. He retired in 1919, but served as chairman of the Board of Directors from then until his death.

Mr. Cox designed and built a variety of machinery for grinding, planing, and drilling, introducing many new features. He was awarded the John Scott Legacy Medal by the Franklin Institute for his grip-socket invention which consisted of a grip chuck for taper shanks to keep them from pulling out of the sockets. He was trustee of the Case School of Applied Science, chairman of the Cleveland Grade Crossing Commission, and director and vice-president of the Cleveland Chamber of Commerce and The Cleveland Trust Company. He became a member of the A.S.M.E. in 1881, and belonged to the Mayflower Society of New York, the Ohio, Union, Country, Mayfield, and Engineers Clubs of Cleveland, the Essex County Country Club in Massachusetts, the Midwick Country Club of Los Angeles, and the Engineers Club in New York. His religious faith was Episcopalian, and he was particularly interested in photography, yachting, and golf. In 1878 he married Ellen Atwood Prentiss, and she, together with three children, Samuel Houghton and Jacob Dolson Cox, and Jeanette Prentiss (Cox) Morrill, survive him.

EDWIN FRANCIS CREAGER

Edwin Francis Creager was born on September 24, 1866, at Harrisburg, Pa., the son of Calvin Wesley and Henrietta Maria (Culmery) Creager. From the age of eleven he earned his own living. He learned the drug business from J. W. Hill & Son of Senatobia, Miss., and subsequently worked for Charles Boyd, at Fort Smith, Ark., for three years as assistant registered pharmacist at Springfield, Ohio, and for H. B. Cochran, at Lancaster, Pa.

In 1886 and 1887 he was night operator and inspector for the Central Union Telephone Company. The next six years were spent in electric light and power work. After serving an apprentice he was advanced through various positions to that of plant manager for the Edison Electric Illuminating Company. Among the plants at which he was stationed were those at Renovo, Lancaster, Williamsport, and Danville, Pa. He combined two plants at Danville, and also did some work at the Sunbury plant. As field man for the southeastern district of the company he covered Delaware, Maryland, the Virginias, the District of Columbia, and the Carolinas. During this period the first electrically driven bridge reamer was designed and built at the Edgemoor Bridge Works, Wilmington, Del., in accordance with his suggestions. He also installed the first searchlights on several coastwise vessels.

Mr. Creager was transferred to the Pacific Coast in 1889. For a time he was in charge of wiring in San Francisco. He built and installed a system of lighting dimmers at the Alcazar Theater there, and designed several other theater lighting novelties still in use. He was in charge of the building of the first Sprague electric railway west of the Rockies, at Sacramento, Calif., and installed the first mine pumping plant electrically driven, at the Gover Mine, in Ione County, Calif.

Mr. Creager returned to the East in 1892 and opened a model shop, known as the Acme Electric Works, at Lancaster, Pa. He sold the business to the Hubley Manufacturing Company two years later, and from then until 1906 was employed by that company, being advanced from pattern foreman to manager. This company was known as the largest iron toy and novelty company in this country at that time. During these years Mr. Creager developed the manufacture of light gray iron castings for the electrical and specialty trade.

In 1906 Mr. Creager again went into business for himself in Lancaster, specializing in automotive and electrical contracting. He also did some consulting work, in connection with which he was engaged by the Hamilton Watch Company to move the plant of the American Telegraphone Company from Wheeling, W. Va., to Springfield, Mass. In 1910 he disposed of his Lancaster business and went to Springfield as general manager of the American Telegraphone Company.

Three years later he left Springfield to enter the engineering department of the Remy Electric Company at Anderson, Ind. He was soon made assistant factory manager and subsequently was promoted to the position of works manager. During the five years he spent with this company its output was increased eleven times and the number of employees two and one-half times. He developed a number of special machines and operations for coil winding, condenser making, presswork, etc.

In 1919 and 1920 he was engaged by the Ott Grinder Company, of Indianapolis, Ind., for which he increased the output from eight to twenty-five machines per month with no increase in the number of employees.

Mr. Creager next became works manager of the Hill Pump and Turbine Works Division of the Midwest Engine Company, at Anderson, Ind. He reduced the operating force materially without decreasing production, and increased the tensile strength of the iron castings from 18,000 to an average of 30,000 pounds. At the same

time he had charge of the buildings, machinery, and personnel of the Indianapolis plant and worked on various engineering problems, including the construction of fireboats for Philadelphia, New Orleans, Norfolk, and Baltimore. He had charge of the installation of the high-pressure fire station at Detroit and the sewage disposal plants at Spring Wells, Detroit, and Indianapolis, for which he built centrifugal pumps to a capacity of 25,000 gal. per min. He also supervised the installation of the city water pumping plant at Bismarck, N. D., and extensions at Springfield, Ill., and designed two 550-lb., 1500 gal. per min. bronze multistage pumps used for operating the hydraulic shears, etc., at the plant of the Otis Steel Company at Cleveland. These were the first pumps of this pressure and capacity used for such work in the United States.

In 1925 the Otis plant changed hands and Mr. Creager was engaged by the Barber Manufacturing Company at Anderson as designing engineer to develop springs and other parts for the automotive and furniture industries. Owing to poor health resulting from a nervous breakdown and heart trouble he resigned his position in 1927 and went to Springfield, Mass., for a rest. He returned to Lancaster late in 1928 and his death occurred there on April 28, 1930. Surviving him are his widow, Clara Augusta (Wettig) Creager, of Lancaster, whom he married in 1892, and one son, Frederick Leon, of Merchantville, N. J.

Mr. Creager joined the A.S.M E. as an associate in 1919 and was promoted to full membership in 1925. He also belonged to the Society of Automotive Engineers and the American Institute of Electrical Engineers, as well as the Masonic fraternity, Elks, and Odd Fellows. He was a member of the Presbyterian faith, fond of hunting and fishing, and interested himself in collecting early mechanical devices. He held the first United States patent to bear descriptive matter on the drawing. He contributed a number of articles to the *American Machinist*, among them one on the "Relation of the Stroke of the Press to the Life of the Die."

JAMES KENMORE CULLEN

James Kenmore Cullen, president of The Niles Tool Works Company, Hamilton, Ohio, and a member of the executive committee of The General Machinery Corporation, died at Hot Springs, Va., on July 31, 1930, of cerebral hemorrhage. He was born in Cincinnati, Ohio, on February 18, 1853, the son of William and Jane (Brocas) Cullen. He received his education at the Cincinnati High School, Currans Preparatory School in Cincinnati, and the Ohio Mechanics Institute. He also served an apprenticeship from 1870 to 1873 in the shops of the Cincinnati, Hamilton & Dayton Railway Co. He then entered his father's jobbing shop where he remained for two years. From 1875 to 1879 he was foreman and draftsman for the Cincinnati, Indianapolis, St. Louis & Chicago Railroad, at Cincinnati.

In 1879 he became foreman and superintendent of The Niles Tool Works Company, at Hamilton, where he remained until 1886 when he was made manager of the Chicago Branch. He was advanced to the position of secretary in 1894 and to that of president in 1900, when he was also elected vice-president of the Niles-Bement-Pond Company. He was president of the latter company from 1915 to 1927. Mr. Cullen had also served as president of Pratt & Whitney Co., Hartford, Conn., John Bertram & Sons Co., Canada, The Miami Foundry Company, Miamisburg, Ohio, and the Cullen & Vaughn Co.

He became a member of the A.S.M.E. in 1886 and also belonged to the Engineers Club, Lotus Club, Machinery Club, and Railroad Club, all of New York, N. Y. He was a thirty-second degree Mason and a Presbyterian. In 1879 he married Addie E. Barns, who died in 1928. He is survived by a son, William B. Cullen, of Springboro, Ohio.

WILLIAM WARREN CUMMINGS

William Warren Cummings, consulting engineer for the Industrial Appliance Company, Boston, Mass., died at Hanover, N. H., on April 5, 1930. He was born at Woburn, Mass., on September 13, 1864, the son of James Otis and Susan Celina (Bennett) Cummings. He was graduated from the Rensselaer Polytechnic Institute in 1884 with the degree of C.E.

Mr. Cummings began his professional experience as assistant professor of mechanics at Rensselaer following his graduation. In 1890 he conducted a private practice as consulting engineer at Woburn, Mass., and was also city engineer there until 1892. He was then assistant city engineer of Troy, N. Y., for a year, and assistant engineer to M. R. Sherrard and draftsman with L. E. Gurley in New York in 1893.

In 1894, Mr. Cummings returned to the teaching profession for a year as assistant professor of mathematics and surveying at the Colorado School of Mines in Golden. He again entered private consulting practice in 1895 at Woburn. He did work in connection with the Massachusetts State Boundary Survey in 1898, and was chief engineer in charge of erection for the New England Gas & Coke Co., Everett, Mass., and the Massachusetts Pipe Line Gas Company, Boston, from 1899 to 1901. In 1903 he became assistant (and later superintendent) of the Isolated Light and Power Department of the Edison Electric Illuminating Company in Boston. He was connected with the Boston Consolidated Gas Company as assistant manager of the commercial department from 1906 to 1910, as manager of the industrial fuel department from 1915 to 1921, and as engineer of utilization from then until 1924. At that time he became consulting engineer, specializing on the industrial use of gas, for the Industrial Appliance Company of New England.

Mr. Cummings constructed three tunnels under the Charles and Mystic Rivers and a 42-in. double pipe line in Boston's congested streets in winter. His work as consulting engineer also included coke oven and railroad and mill construction.

He became a member of the A.S.M.E. in 1905 and was also a member of the American Society of Civil Engineers, the American Gas Association, the American Society for Steel Treating, the Boston Society of Civil Engineers, and the American Institute of Electrical Engineers. He belonged to the St. Thomas Church at Hanover, N. H. In 1898 he married Alice Jeeves. She, together with four children, Carl Herrick, William Warren, Jr., Harry Blanchard, and Doris Elizabeth Cummings, survive him.

WARREN JOHN JOSEPH DARWENT

Warren John Joseph Darwent, whose death occurred in Schenectady, N. Y., on July 19, 1930, was born in Jersey City, N. J., on June 15, 1898, the son of John Peterson and Alice Maude (Sutton) Darwent. He received a degree of B.S. in mechanical engineering from Rutgers College in 1921, and took a summer course in chemical engineering at Columbia University.

Before graduation he was employed by the Wright Martin Aircraft Corporation, New Brunswick, N. J., and the Singer Manufacturing Company, Elizabethport, N. J., and he worked for the latter as draftsman until 1925. For the next two years he was connected with the Consolidated Gas Company in New York and from then until 1930 was engineer for the Certainteed Products Corporation of Philadelphia. At the time of his death he was in the employ of the American Blower Company, in Schenectady, N. Y.

Mr. Darwent became a junior member of the A.S.M.E. in 1921 and belonged to the Lambda Chi Alpha fraternity. He was an Episcopalian and interested particularly in music, playing several instruments. In 1927 he married Ruth L. Skidmore, and she, together with their daughter, Joan Ruth, survive him.

EZRA D. DAVIDSON

Ezra D. Davidson, a native of Ansonia, Conn., died in that city on December 30, 1930, after an illness of several months. Mr. Davidson was born on December 5, 1886, the son of James H. and Laura B. Davidson. After completing his high school education he entered the plant of the Farrel Foundry & Machine Co., later known as the Farrel-Birmingham Company, of Ansonia. He supplemented his early education with Y.M.C.A. and correspondence school courses, and at the time of his death had become sales engineer for the company.

For many years Mr. Davidson was prominent in athletics in Ansonia. He was a member of the championship team of the Farrel Foundry during the existence of the Industrial Basketball League in Ansonia and also played on the basketball and baseball teams of the local Y.M.C.A. In sports as in his business relations, he was popular for his fairness, and was known as a "square shooter." Mr. Davidson was a member of the Wepawaug Country Club of Milford, Conn.

Mr. Davidson became an associate member of the A.S.M.E. in 1921. He was an authority on rubber and rubber machinery, and in work on the Safety Code for Rubber Machinery represented the Society on the International Association of Industrial Accident Boards and Commissions and the National Safety Council.

In the Masonic fraternity Mr. Davidson, who had attained the rank of the 32d degree, was a very prominent figure, belonging to local groups in Mount Vernon, New Haven, and Bridgeport, as well as Ansonia. He was also a member of the First Baptist Church at Ansonia.

Mr. Davidson's wife, Louise H. Davidson, died about four years ago. He is survived by three daughters, Madeleine Huson, Lois Gertrude, and Marian Winifred Davidson.

WILLIAM J. DELLES

William J. Delles died suddenly of heart trouble at his home in Schenectady, N. Y., on May 22, 1930. He was executive engineer in the turbine engineering department of the General Electric Company in that city. He was born in Rochester, N. Y., on September 4, 1871, the son of Peter John and Antoinette (Spitzberg) Delles. He received his education at the Mechanics Institute at Rochester, N. Y. From 1892 to 1898 he served as apprentice and journeyman molder. He then entered the employ of the General Electric Company and until 1922 served successively as draftsman, section leader, and foreman in charge of mechanical design in the direct current department; mechanical engineer in the assistant manager's office engaged in the development of special machinery for the factory, and standardization and improvement of methods of production; and assistant engineer of the turbine engineering department. As executive engineer in the latter department he was responsible for the design, manufacture, installation, and operation of steam turbines.

Mr. Delles became a member of the A.S.M.E. in 1924 and was a member of the Quarter Century Club of the General Electric Company and the Knights of Columbus. He was married to Lenore C. Driscoll in 1918, and she, together with two children, William James, Jr., and Rose Margaret Delles, survive him.

FREDERICK WILLIAM DERBYSHIRE

Frederick W. Derbyshire, owner of the firm of F. W. Derbyshire, Waltham, Mass., died on December 30, 1930, following an operation. He was the son of William Henry and Ann (Briley) Derbyshire, and was born in Lowell, Mass., on September 23, 1859. He attended the public schools of Waltham, Mass., and after serving an apprenticeship with the American Watch Tool Company there, was employed by that company as foreman and later as assistant superintendent in connection with the design and supervision of lathes and automatic machinery used in manufacturing watches and clocks. In 1899 he became connected with the Pratt & Whitney Co., Hartford, Conn., as foreman of its model department and from 1901 to 1911 again was employed by the American Watch Tool Company in charge of the design and manufacture of machine tools. He established his own firm in 1911 to manufacture lathes and attachments for watch, clock, and instrument work.

Mr. Derbyshire became an associate member of the A.S.M.E. in 1918 and was also a member of the Engineering Societies of Boston and very active in the Masonic fraternity.

In 1885 he married Clara Jane Stackpole, who died in 1912. Two children, Frederick W., Jr., and Elna Derbyshire, survive him.

JAMES G. DORNBIRER

James G. Dornbirer, president of the Dornbirer Machine Tool Company, which he established in 1929, died on November 27, 1930. He was born in Huron County, Ohio, on March 4, 1867, the son of Jacob and Elizabeth (Trott) Dornbirer. After attending the public schools of Sandusky, Ohio, he served as an apprentice machinist with D. June & Co., Fremont, Ohio, and the Warner & Swasey Co., Cleveland. He then ran a machine shop at Marion, Ind., from 1889 to 1895. The next three years he spent at Rose Polytechnic Institute at Terre Haute, Ind. Completing his studies there he started the J. G. Dornbirer Machine Co. in Cleveland in 1898, for the manufacture of special machinery, and automatic and semi-automatic labor-saving machinery. He was associated with G. W. Ford in the organization of the Cleveland Planer Works, and designed a line of planers and served as general manager of that company. He also designed a line of horizontal boring machines built by the Cleveland Machine Tool Company, and invented and patented two prime movers.

Mr. Dornbirer was a contributor to the *American Machinist* and *Machinery*, an organizer and director of the Northern National Bank, and a director of the Equity Savings & Loan Co., the International Oil Corporation, the Northern Savings & Trust Co., the Cleveland Art Museum, and the Cleveland Chamber of Commerce.

He became a member of the A.S.M.E. in 1913 and also was a member of the Rose Tech Club, the Cleveland Athletic Club, and the Cleveland Engineering Society. He was a Lutheran by faith. He married Laura E. Ridenour of Cleveland, and she, together with three children, Stanton, Norman, and James Dornbirer, survive him.

HENRY DRESES

Henry Dreses, retired, died at the age of 77 at Marburg, Germany, on July 5, 1930, of cancer. He was born in Soest, Germany, on August 24, 1853, the son of Anton and Maria K. (Schaffstein) Dreses. After public school training in his home town, he attended the Technikum at Einbeck, Germany, and continued his studies in mechanical engineering at the Royal Polytechnical School at Aachen, Germany. He served as an apprentice in a machine shop at Soest for three years, and worked as a machinist on sewing machines and paper machinery for two years. He was draftsman and shop assistant in rolling and tin sheet mills at Husten, Germany, for a short time, after which, in 1881, he came to the United States and was employed as a machinist by Ohl & Co., manufacturers of machine tools and hydraulic presses, of Newark, N. J. Subsequently he was connected with Smith, Beggs & Rankin, St. Louis, Mo., manufacturers of Corliss and mill machinery, Fay & Co., manufacturers of wood-working machinery, Cincinnati, Ohio, and as machinist and draftsman for the Ahrens Fire Engine Company and Lodge & Barker, of Cincinnati. He became a partner in the firm of Dreses & Adams, in Cincinnati, in 1885, operating a machine shop, but gave up this connection in 1886 when he accepted a position as chief draftsman and designer for Lodge & Davis (now American Tool Works Company), in that city. In 1895 he became proprietor and manager of the Dreses Machine Tool Company, in Cincinnati, and continued in this work until his retirement in 1927.

Mr. Dreses took out numerous patents on lathes and radial drills. He was a director of the Cincinnati Altenheim and became a member of the A.S.M.E. in 1914. Other fraternal organizations and clubs to which he belonged included the Cincinnati Club, Western Hills Country Club, Masons, Germanistic Society, of which he was treasurer, and the Germany Literary Club. He took a keen interest in natural science, especially in astronomy and geology, on which he lectured repeatedly before the German Literary Club. He also was a familiar figure at Cincinnati concerts. He was unmarried.

JOHN A. DUGAN

John A. Dugan, associate professor of mechanical engineering at the Catholic University of America, died at the Georgetown Hospital, Washington, D. C., on June 19, 1930, following an operation for appendicitis. He was born in Washington, on February 19, 1890, the son of Patrick Henry and Nora (Feeney) Dugan. He received his education at Washington public and technical high schools, and at the Catholic University of America, which conferred upon him the degree of B.S. in M.E. in 1915, M.A. in 1924, and M.E. in 1925.

In 1915 and 1916 Mr. Dugan was connected with the Pennsylvania Iron Works Company, Eddystone, Pa., in charge of heat-treating shrapnel. He became assistant to the shop foreman of the Baldwin Locomotive Works at Eddystone in 1916, working on heat-treating 220 and 270-mm. French shells, and in 1917 was toolmaker and night foreman at the Remington Arms Company in that city.

From 1917 to 1919 Mr. Dugan served as captain in the Transport Service of the U. S. Army. After the war he returned to his alma mater as instructor in mechanical engineering. He was commissioned a major in the Officers' Reserve Corps in 1929.

In collaboration with Louis H. Crook, Mr. Dugan prepared a number of papers on stresses in rail joints and fish-plates due to welding which were part of the seventh annual report of the Welded Rail Joint Committee of the American Electric Railway Association.

Mr. Dugan became an associate-member of the A.S.M.E. in 1921 and was also a member of the Washington Society of Engineers. His fraternal and club memberships included the University Club, Congressional Country Club, American Legion, and Knights of Columbus. In 1919 he married Oriel Gulli, of Washington, by whom he is survived.

THOMAS COLEMAN DU PONT

Thomas Coleman du Pont, former Senator from Delaware and one of the foremost financiers of this country, died at his home in Wilmington, Del., on November 11, 1930. He had been in ill health since 1927 when he was operated upon for cancer of the throat.

He was born in Louisville, Ky., December 11, 1863, the son of Antoine Bidermann and Ellen Susan (Coleman) du Pont. He was a great-great-grandson of Pierre Samuel du Pont de Nemours, a distinguished French statesman and economist, whose son founded the du Pont powder industry in Delaware in 1802. Coleman du Pont (who dropped the "Thomas" from his name early in life) was educated at Urbana (Ohio) University, Chauncy Hall School, Boston, and the Massachusetts Institute of Technology, where he was graduated as an engineer in 1884. He was a prominent athlete in his college days, playing baseball and football, stroking the crew, and engaging in track events.

Mr. du Pont was predominantly a builder and organizer. He made one fortune after another in the coal-mining business, the steel industry, street railways, the du Pont explosive works, insurance, hotels, office buildings, and real estate. His was the instinct to create and organize which more than once brought him back to active busi-

ness when he had "retired." Except for the hotel and real-estate operations in his later years, however, he always disposed of a project as soon as he had put it on a successful basis, his interest turning to something new.

His career began with the mining industry, where he started at the bottom as a miner in the employ of the Central Coal & Iron Co., Central City, Ky. He dug coal, drove mules, and performed other similar tasks, and also became a member of the union, known as the Knights of Labor. He rose through various positions until he became president of the company and developed both the company and the town where it was located. At the age of thirty he abandoned the mining business and became manager of the Johnson Steel Company at Johnstown, Pa. This company afterward became the Lorain Steel Company, now a subsidiary of the United States Steel Corporation.

When in Johnstown, Mr. du Pont became interested in street railways and went into the business on a large scale, becoming president of the Johnstown line and purchasing other lines in New York, New Jersey, and Alabama. He left the steel business in 1900 and became president of various coal and iron corporations in Kentucky, including the McHenry Coal Company, and the Main Jellico Mountain Coal Company.

At the age of thirty-seven he determined to retire from business, and went to live in Wilmington, but two years later accepted the presidency of E. I. du Pont de Nemours & Co., at the request of his kinsmen. Eugene du Pont, head of the company, had died, and his brothers, who did not care to take his place, were about to sell the business outside of the family. Mr. du Pont and his cousins, Pierre S. and Alfred I. du Pont, agreed to take over the management in order to keep the business in the family.

Under Mr. du Pont's presidency from 1902 to 1915, the company was reorganized on a highly efficient basis which enabled it to produce an enormous amount of war materials when the World War began, and its by-products were developed to a point where it is now able to turn out an astonishing number and variety of synthetic products—leather and ivory substitutes—in addition to powder and explosives.

In 1915, Mr. du Pont resigned as president after selling his holdings in the company to a syndicate headed by Pierre S. du Pont. On leaving the business, Mr. du Pont, who had become chairman of the Equitable Office Building Corporation, began real-estate operations. He built the Equitable Building, at 120 Broadway, New York, and purchased the controlling interest in the Equitable Life assurance Society, mutualized the organization and then disposed of the stock to the policy holders without profit on the investment. In association with Lucius M. Boomer, Mr. du Pont organized a hotel chain, building some new hotels and buying others. These included the Waldorf, McAlpin, the new Savoy-Plaza in New York, the New Willard in Washington, and the Bellevue-Stratford in Philadelpnia. The Boomer-du Pont interests were also associated in the Louis Sherry and Savarin restaurants. Mr. du Pont built the du Pont Hotel and the du Pont office building in Wilmington, and was heavily interested in hotel and real-estate projects in Florida.

From the beginning of his residence in Delaware, Mr. du Pont manifested interest in state politics and by 1904 was recognized as one of the Republican leaders of the commonwealth. He held the rank of brigadier-general of the National Guard of Delaware under five governors, served for years as chairman of the Republican State Committee of Delaware, and from 1904 until 1924 was a member of the Republican National Committee. During the campaign of 1908 he was in charge of the speakers' bureau of the national organization.

In 1916 Mr. du Pont was a candidate for the Republic nomination for President and received thirteen votes on the second ballot in the national convention at Chicago. In 1921, Governor William D. Denny of Delaware appointed him United States Senator to fill the vacancy caused by the resignation of Senator J. O. Wolcott. At the expiration of his term he was nominated for election to the Senate, but was defeated. However, he was elected to the Senate for a six-year term in 1924. He resigned in 1928 because of ill health.

For years an enthusiast on the subject of good roads and a founder of the National Highway Association, Mr. du Pont, at his own expense, built and presented to the State of Delaware a $4,000,000 highway, known as the Coleman du Pont Boulevard, extending 100 miles from Wilmington to Selbyville. He was a generous giver to educational and philanthropic projects, his largest known donation having been $1,000,000 to the Massachusetts Institute of Technology, of which he was a trustee. In 1918 Mr. du Pont became president of the Industrial Finance Corporation, which controlled the Morris Plan of lending money to small borrowers.

He was a clever worker on wood and metal, indulging in this as a hobby. In his several residences were many examples of his handicraft.

Mr. du Pont became a member of the A.S.M.E. in 1906. He was also a member of the Engineering Association of the South, the American Academy of Political and Social Science, the Engineers and Architects' Club, and the American Institute of Mining and Metallurgical Engineers. His social clubs included the Rittenhouse, in Philadelphia; the Metropolitan, in Washington; the Metropolitan, New York Yacht, Union League, and Bankers, in New York; and the Wilmington and Wilmington Country, in Wilmington.

Mr. du Pont was married in 1889 while working in the Kentucky coal mines, to a second cousin, Alice du Pont. They had two sons and three daughters. He is survived by his widow and four children as follows: Mrs. H. S. Meeds, Mrs. C. Douglas Buck, Mrs. John Willcox Donaldson, Jr., and Frank V. du Pont.

WILLIAM P. EALES

William P. Eales, assistant superintendent of the Engineering and Inspection Division, Travelers Insurance Company, Hartford, Conn., died at East Hampton, Conn., on January 25, 1930. He was born at Alpena, Mich., on July 16, 1871. After receiving a high school education he became an apprentice machinist and boiler maker for Warren & McDonald, at Alpena, in 1885. From 1888 to 1890 he was employed by David Crippen, Alpena, as a machinist and boiler maker, and by the Walker Manufacturing Company, in Cleveland, Ohio. The next three years he spent as apprentice engineer on United States merchant ships, and from 1893 to 1896 he was assistant engineer in charge of watch for several steamships. For eight years, beginning in 1897, he was chief engineer of the steamships, *Sheriffs*, *City of London*, *Indiana*, and *Eastland*.

Mr. Eales joined the Travelers Insurance Company as an inspector at Chicago in 1905. He became supervising inspector of the Philadelphia territory in 1921, and was called to the home office in Hartford as assistant superintendent of the engineering and inspection division in 1916.

Mr. Eales, an associate of the A.S.M.E. since 1917, served on the Boiler Code Committees on Miniature Boilers and Rules for Inspection. For thirteen years he was chairman of the Examining Board for Boiler and Elevator Certificates for the State of Pennsylvania. He also acted as a consulting engineer for the Labor Department for the State of Pennsylvania in connection with the many outstanding safety questions of the department.

Mr. Eales was also a member of the Engineering Society of Western Pennsylvania, and a Knight Templar and thirty-second degree Scottish Rite Mason. He took a keen interest in farming, and possessed a farm of about 165 acres where he spent practically all his leisure time. He is survived by his widow. They had no children.

VICTOR BYRON FAULKNER

Victor Byron Faulkner, assistant plant manager for the National Aniline & Chemical Co., Buffalo, N. Y., died of pneumonia on November 15, 1928. He was born in Norwich, England, on July 1, 1890, the son of Frederick W. and Caroline B. (Dimbleby) Faulkner. He was educated at King Edward VI School, and the High School and Commercial School at Norwich, England, and after coming to the United States in 1907 took courses in factory and business management through the Alexander Hamilton Institute and Industrial Extension Institute.

His first business connection in this country was with the Eastman Kodak Company where he was engaged until the beginning of the World War. During the War he was located at the Niagara and Churchill plants of the Curtiss Aeroplane & Motor Corp., in charge of tool design and machine shops, engine shops, the wood-working shop, aeroplane assembly, heat treating, and the metallurgical laboratory. In 1919 he became associated with the National Aniline & Chemical Co. which he served successively as maintenance supervisor, plant engineer in charge of design, engineering development, construction, maintenance, and power plants, and assistant plant manager. He was recognized as one of the outstanding technicians in the American chemical industry.

He became a member of the A.S.M.E. in 1927. He was active in the Masonic fraternity and in religion an Episcopalian.

In 1919 he married Elizabeth L. Waterstraw, who, together with two children, Annette C. and Jeannette L. Faulkner, survive him.

WILLIAM EDWARD FINKERNAGEL

William Edward Finkernagel, assistant superintendent of power at the Hunts Point Station of the Consolidated Gas Company, New York, N. Y., died on July 14, 1930. He was born in New York on June 27, 1895, the son of Frederick William and Wilhelmina Elizabeth (Scheid) Finkernagel. He received his education in the Stuyvesant High School of New York and at Cornell University, from

which he was graduated with the degree of M.E. in 1920. Upon graduation he became engineer on heat power work and construction for Bradford & Tile, at Bradford, Pa. In 1921 he was made assistant superintendent of general engineering work for the Central Union Gas Co., New York, and in 1924 became assistant superintendent of the Astoria Light, Heat & Power Co., in charge of boilers, power house, and electric coal handling. His association with the Consolidated Gas Company began in 1926.

Mr. Finkernagel became a junior member of the A.S.M.E. in 1922 and an associate member in 1926. He married Frieda B. Bansemer in 1928, and she, together with two children, William E., Jr., and Robert Henry, survive him.

EDWARD CUMBERLAND FISHER

Edward Cumberland Fisher, district sales manager at St. Louis, Mo., for the American Locomotive Company, died at Rochester, Minn., on February 17, 1930. He was a Virginian by birth, having been born in Powhatan County, on May 2, 1875, the son of Charles and Maria (Jervey) Fisher.

Mr. Fisher supplemented his early education in the schools of Richmond, Va., with engineering courses at the Night School of the Virginia Mechanics Institute of Richmond, and later was night instructor there for several years.

After serving an apprenticeship as a machinist with the Framville & Powhatan R. R., at Chester, Va., from 1891 to 1896, Mr. Fisher secured employment at the Petersburg Iron Works for about a year. He was foreman on outside construction work for the Richmond Iron Works and in the erecting shop of the Southern Railroad at Spencer, N. C., from then until 1898, when he became shop engineer and instructor of an apprentice class in drawing and mathematics for the Chesapeake & Ohio R.R. at Huntington, W. Va.

He entered the employ of the Richmond Locomotive Works as draftsman in 1899 and was identified with that organization and its successor, the American Locomotive Company, continuously until his death. In 1910 he was transferred from Richmond to the Rogers Works at Paterson, N. J., as superintendent. In 1913 he was made manager of the Cooke Works, also located at Paterson, and in 1916 manager of both works. In 1917 he was transferred to Pittsburgh, Pa., as manager of the Pittsburgh Locomotive Works, also one of the plants of the American Locomotive Company.

During the World War Mr. Fisher was a speaker in behalf of the Liberty Loan campaign, and was a member of the Federal Secret Service.

After the War Mr. Fisher was sent on special work by the American Locomotive Company to South America, where he and his family made their home at Rio de Janeiro, Brazil. Later he was transferred to Johannesburg, South Africa, in the interests of the company. In 1922 he returned to the United States and opened offices in St. Louis, Mo.

Mr. Fisher became a member of the A.S.M.E. in 1917. He was a vice-president of the St. Louis Rotary Club, and while in South Africa he organized the first Rotary Club on that continent, at Johannesburg. He was a member of the St. Louis Chamber of Commerce, vice-president of the St. Louis Traffic Club, and a director of the St. Louis Railway Club. He was also a member of the St. Louis Engineering Society and Engineers Club of St. Louis and belonged to the Bellerive Country Club of St. Louis, the Missouri Athletic Association, the Louisville (Ky.) Country Club, the Pendennis Club of Louisville, and the Scottish Rite Club, being a Scottish Rite Mason and Shriner. He was a vestryman of St. Michael and St. Georges Episcopal Church, a member of the Missouri Society of the Sons of the American Revolution, and was a State Commander of the Sons of Confederate Veterans.

In 1905 Mr. Fisher married Anne Hinton Richmond. She and two children, Edward C., Jr., and Elizabeth Lewis, survive him.

CHARLES CARROLL GARDNER

Charles Carroll Gardner, superintendent of the Massachusetts Cities Realty Company, Haverhill, Mass., died on December 3, 1930, at the Gale Hospital in that city, following an operation. He was born at Hanover, Mass., on February 9, 1892, the son of John Davis and Bethia Cushing (Foster) Gardner. He received his education through the International Correspondence Schools.

Mr. Gardner's professional career began in 1910 as a power plant operator in Massachusetts. He advanced in grade to that of first class engineer. In 1917 he became chief engineer of the Taunton Gas Works, Taunton, Mass. Two years later he entered the employ of the Chandler Oil Cloth & Buckram Co., at East Taunton, where he installed new steam and power generating equipment. In 1920 he contracted with the Keene Woodenware Company and Keene Shoe Company at Keene, N. H., to revamp their power systems. In 1921 he became resident engineer for the W. H. McElwain Co., Manchester, N. H., and in the next year held a similar position with the International Shoe Co., at its Burke Tannery, Morganton, N. C. In 1923 he was sales representative for the Republic flow meters and recorders, and from 1924 to 1925 plant engineer and chief engineer of the National Fireworks Mfg. Co., Hanover, Mass. After two years as salesman for the Walworth Co., Boston, Mass., specializing in industrial and greenhouse heat layout work, he attempted contracting in this field but was unsuccessful because of insufficient capital. He therefore accepted a position with the Baker Supply Company, of Cambridge, Mass., a subsidiary of the R. H. Baker Construction Co., to develop and direct the mechanical and sales department of the firm.

Mr. Gardner became a member of the A.S.M.E. in 1929. He was also an active member of the National Association of Stationary Engineers, having served as chairman of the New England States Education Committee, as president in 1919, and as Massachusetts deputy at the New England Convention in 1920. He belonged to Masonic organizations in Taunton and the Rotary and Kiwanis Clubs of Haverhill, Mass., and was a member of the First Baptist Church of Hanover, Mass.

He married Maude Woodworth Shultz in 1911, and she, together with their children, Laura C., Lois C., Phyllis E., and Charles Robert Gardner, survive him.

WILLIAM LOWRY GILLETT

William Lowry Gillett, consulting engineer, New York, N. Y., died on February 24, 1930, of pneumonia. He was born at Evansville, Ind., on December 9, 1879, the son of Simeon Palmer and Grace Ann (Lowry) Gillett. He received the degree of A.B. from the University of the South, at Sewanee, Tenn., in 1900, and a B.S. from the Massachusetts Institute of Technology, three years later.

After graduation he entered the employ of the General Chemical Company of New York, where he held various positions in the construction department and had charge of mechanical and electrical power-house design and the operation of power plants. Later he was made chief engineer in charge of engineering and construction for the company. Since 1914 he had done consulting work, the Nichols Copper Company and the Phosphate Mining Company being among his clients.

Mr. Gillett owned or had pending several patents on chemical apparatus. During the World War he worked on air-nitrate at Sheffield, Ala.

He became a junior member of the A.S.M.E. in 1904 and a member in 1917. He also belonged to the Engineers Club, University Club, Nassau Country Club, and the Phi Delta Theta fraternity. He was a member of Christ Episcopal Church at Oyster Bay, Long Island. In 1909 he married Enid Locke Gillett, and she, with one daughter, Enid, survive him.

WALTER FRANCIS GOODRICH

Walter Francis Goodrich died at his home at Little Brickhill, Bucks, England, on July 21, 1930. Mr. Goodrich was born in London on January 7, 1872, and was privately educated. He secured experience in combustion engineering under Meldrum Brothers, Manchester, for two years, and then spent three years in Scotland as engineer representative of the company. He returned to London in 1898 to represent the company there, and remained in that position until 1908, when he founded the firm of Goodrich & Hamlyn, Ltd., for the design of furnaces and complete boiler installations for municipalities and industrial undertakings.

Mr. Goodrich served as director for this company until 1919, when he was appointed director of the Ferguson Superheaters, Ltd. During the six years of his association with the Ferguson Superheaters, he designed superheaters for special processes, introduced the use of superheated low-pressure steam in connection with vertical gas retorts for the production of water gas, and served as manager of the company for some time.

In 1920 Mr. Goodrich also became identified with the Spearing Boiler Company, Ltd., London, which later became the Vickers-Spearing Boiler Company, and still later the Vickers Boiler Co., Ltd. He served at first as contract engineer and manager, later chief engineer, advising upon questions of fuels, firing, and combustion, and responsible for the layout of boiler house equipment for large modern power stations. During the last few years of his life he practiced as a consulting engineer, with an office in London.

Mr. Goodrich became a member of the A.S.M.E. in 1926. He was also a Fellow of the Institute of Sanitary Engineers and a member of the Institute of Fuel Economy Engineers.

JOSEPH AIMÉ GODEFREY GOULET

Joseph Aimé Godefrey Goulet, mechanical engineer for the Canadian General Electric Company, Peterborough, Ontario, Canada, died suddenly of heart disease on December 16, 1929.

Mr. Goulet was a native of Canada, having been born at St. Eustache, Quebec, on October 22, 1868, the son of J. M. and Emma (Dorion) Goulet. He attended Bourget College, and received a B.Sc. degree in Mechanical Engineering from McGill University in 1890.

The first ten years of Mr. Goulet's engineering work were spent partly in the United States and partly in Canada. He was connected for a year each with the Deane Steam Pump Company, Holyoke, Mass., and the Northey Manufacturing Company, Toronto, was engaged in work for the Columbian Exposition at Chicago in the agricultural machinery department in 1893 and 1894, and spent some time in taking soundings of the Saguenay River. From 1894 to 1896 he was assistant superintendent of dredging and also was in charge of designing and construction at the government shipyard at Sorel, Quebec. The next three years were spent as mechanical engineer and chief designer with The Northrup Loom Company of Canada, Valleyfield, Quebec, and in 1899-1900 he was employed in a similar capacity by The Draper Corporation, located at Hopedale, Mass.

From 1900 to 1901 Mr. Goulet was connected with Isaac Mautner & Sohn, of Vienna and Budapest, as master mechanic. Since then he had been located in Canada, for two years as designing draftsman at the Montreal plant of the Canadian General Electric Company and the remainder of the time in the position he held at the time of his death.

Mr. Goulet became a member of the A.S.M.E. in 1924 and also belonged to the Engineering Institute of Canada. He is survived by a son, Sifroy Goulet.

MAURICE RODNEY HAMILTON

Maurice Rodney Hamilton, whose death occurred at Upper Montclair, N. J., on November 19, 1930, was a native of Montclair, where he was born on January 21, 1902, the son of William Hamilton and Nellie May (Garrabrant) Hamilton. He attended the Montclair Academy and Stevens Institute of Technology, from which he was graduated with an M.E. degree in 1927. After a few months as apprentice engineer in the shop course of Babcock & Wilcox, Bayonne, N. J., ill health forced him to give up work.

Mr. Hamilton became a junior member of the A.S.M.E. in 1928 and also belonged to the Masonic order. He is survived by his widow, Verna Esther (Frey) Hamilton, whom he married in 1924.

VINCENT G. HAZARD

Vincent G. Hazard, mechanical engineer with the Pusey and Jones Corporation and prominent in the affairs of Wilmington, Del., died at his home at Claymont, Del., on April 13, 1930, after a brief illness. He was born on January 20, 1853, in Philadelphia, the son of Willis Pope and Susan Robinson (Gilpin) Hazard. After studying in a number of different schools, he came under the tutorship of J. Hunter Worrall, graduate of Yale University and later instructor there, and partly through his influence entered the Sheffield Scientific School, Yale University, from which he was graduated in 1874, receiving the degree of Ph.B. in the Mechanical Engineering course. A little later he entered the employ of Pusey, Jones & Co., the name of which was subsequently changed to The Pusey and Jones Company and then to its present form. His first work was that of a draftsman and later he was chief of draftsmen designing paper machinery, field engineer in charge of paper machinery erectors, director of technical correspondence, and editor of *The Super-Calendar*, a monthly house magazine published by the company.

Mr. Hazard was a member of the Central Presbyterian Church in Wilmington and for a number of years was a member of the Board of Trustees, and of the corresponding board of the United First-Central Church. For 16 years he was head of the Wilmington Institute Drafting School, a night school for shop apprentices and others. He was for 22 years a member of the Board of Managers of the Wilmington Institute Free Library and for half that period was also chairman of the Board. He was interested in the Boy Scout movement and had served as a member of the Court of Honor of the Wilmington Council of that organization. He was a life member of the A.S.M.E., having joined the Society in 1882.

Mr. Hazard is survived by one daughter, Mrs. Robert F. Brinton, of Westchester. He was twice married. His first wife was Miss Maria D. Clould and his second wife Miss Anna S. Gelpin, both of Wilmington.

ERNEST K. HEERING

Ernest K. Heering, whose death occurred on February 28, 1930, was born at Osnabouck, Germany, on June 6, 1878. He studied mechanical engineering at the Technische Hochschule, Hanover, Germany, being graduated in 1899 and receiving the degree of Diplom-Ingenieur in 1901.

Mr. Heering was employed in Germany and Austria for some years. After two years as assistant to the chief of the engineering laboratory at the Technische Hochschule he went to Diez, Germany, where he associated himself with a consulting engineer in the design of bridges, ship elevators, and other assignments. From 1903 to 1906 he was employed with Amme, Giesecke & Konegan in the design of hydraulic turbines and dams; during the last year of this connection he was assistant manager of the shops of the company. Subsequently he was located for a time at Hohenelbe, Austria, where he was engaged in the design of hydraulic turbines and governors, and testing of turbines.

After coming to the United States, where he took out citizenship papers in 1916, Mr. Heering was connected for some years with the I. P. Morris Co. (subsequently The William Cramp Shipbuilding Company and now Cramp Morris Industrials, Inc.), at Philadelphia. He was design engineer and later assistant chief draftsman in the hydraulic division.

Mr. Heering returned to Germany for a few years, practising as a hydraulic engineer at Dresden until 1926. He then accepted a position as design engineer with the Birdsboro Steel Foundry & Machine Co., Birdsboro, Pa. Following this he was located for a time in Wilkinsburg, Pa., and then went to the Pacific Coast, where he entered the employ of the Pelton Water Wheel Company in San Francisco. Ill health forced his retirement from active business during the latter part of his life.

Mr. Heering had been a member of the A.S.M.E. since 1917.

WINTER D. HESS

Winter D. Hess, western sales manager, with headquarters at Chicago, for the Builders Iron Foundry, of Chicago, the Glamorgan Pipe & Foundry Co., of Lynchburg, Va., and the Darling Valve & Mfg. Co., of Williamsport, Pa., died of heart failure on February 27, 1930. He was born at Arcola, Ill., on December 14, 1865, the son of Abraham W. and Mary Vail (Marston) Hess. He received his education in the public schools at Evanston, Ill.

He became western sales manager for the Builders Iron Foundry in 1901 and cooperated with civil, gas, mechanical, and hydraulic engineers in solving problems involving the measurement and rate control of the flow of liquids and gases. He specialized particularly in apparatus for pumping stations, filter plants, sewage treatment, chemical works, gas plants, and power plants.

He became a member of the A.S.M.E. in 1921. He was also a member of the Western Society of Engineers. His club memberships included the Big Foot Country Club, Lake Geneva, Wis., the Lake Shore Athletic Club, Chicago, and the Evanston Golf Club, Chicago, of which he was a director. He was a member of the First Congregational Church at Evanston. His widow, Pearl (Nightingale) Hess, together with four children, Chase N., Richard D., Frederick W., and F. Romeyn, survive him.

SAMUEL MURRELL HEULINGS

Samuel Murrell Heulings, whose death occurred at his home in Haddonfield, N. J., on May 15, 1930, was born in Philadelphia, Pa., on October 5, 1859. His parents were Samuel Murrell and Sarah Champion Heulings. He is survived by his sister, Harriet A. Heulings.

Mr. Heulings was well known throughout the dairy world for his sanitation work in that field. The Star Milk Cooler Company was formed at Haddonfield in 1899 for the manufacture of the Star Cooler, invented and patented by Mr. Heulings, and he served the company as general manager until 1910.

The line of Star sanitary dairy apparatus and machinery included, in addition to coolers, strainers and sterilizers, and bottle washers, fillers, and cappers. The first application of hydraulics to dairy machinery was made by Mr. Heulings in automatic hydraulic bottle fillers and cappers. He also designed, constructed, and installed cableways for milk transmission from barns to dairy buildings, and ventilating systems for supplying filtered air. He installed and supervised the operation of power refrigerating and other electrical equipment in dairy plants, and cooperated with architects in the design and construction of a number of dairy buildings and certified milk plants adapted to the sanitary handling of milk and economic operation.

In 1911, Mr. Heulings accepted a position as dairy engineer for the Sheffield Farms of the Slawson-Decker Company, New York. During the twelve years which he spent with this company he made further outstanding contributions to methods and equipment for milk sanitation. He designed, constructed, installed, and operated air filtering and ventilating systems and sterilizing equipment in the Sheffield plants throughout the City of New York and had charge of experimental shops for the company. His process of pasteurizing milk was tested at a plant designed and constructed by him at Bloomville, N. Y., with such success that a similar plant was later erected in the Bronx, N. Y. He gave invaluable assistance to the health commissioner of New York in raising the standards of purity of milk in that city.

Mr. Heulings was also consulting engineer for the United Dairies, Ltd., London, England, for four years.

The American Public Health Association, of which Mr. Heulings became a member in 1917, asked him to serve on its committee on pasteurization, and made him a delegate to the World's Dairy Congress in 1923 where he gave an address describing his continuous holding tanks for the milk pasteurizing process. He was a fellow of the Sanitary Engineering Section of the Association, and had been a member of the A.S.M.E. since 1916.

MERRILL HIBBARD

Merrill Hibbard, president of the Middle States Construction Company, Columbus, Ohio, died on October 16, 1930, at the Grant Hospital in that city, of nephritis. He was born in Cincinnati, Ohio, on December 25, 1875, the son of Samuel E. and Julia E. (Swasey) Hibbard.

Mr. Hibbard was a graduate of the University of Cincinnati, where he obtained the degree of B.S. in C.E. in 1897. For the next three years he worked as rodman, levelman, transitman, and draftsman on new water works at Cincinnati, and on the construction of a pumping station at California, Ohio. From 1900 to 1904 he was connected successively as draftsman on hoisting and conveying equipment for Heyl & Patterson, Pittsburgh, Pa.; erecting engineer of steel structures for McClintic, Marshall Construction Company; and erecting engineer of locomotive and gantry cranes for the Interstate Engineering Company, Cleveland, Ohio.

From 1904 to 1925 Mr. Hibbard was identified with the Jeffrey Manufacturing Company, in which he rose from the position of draftsman to that of chief engineer. He had been with the Middle States Construction Company since 1925, for the past two years as president.

Mr. Hibbard became a member of the A.S.M.E. in 1920. He also belonged to the American Society of Civil Engineers, Tau Beta Pi fraternity, the Masons, Players Club, Athletic Club, Columbus Country Club, and Ohio Society of New York. He was a member of the Trinity Episcopal Church.

He married Emma Copman in 1903, and she, together with a daughter, Adelaide, and his mother, survive him.

CAMPBELL P. HIGGINS

Campbell P. Higgins, for many years connected with Babcock & Wilcox Co., Bayonne, N. J., died at his home in Roselle, N. J., on May 29, 1930.

Mr. Higgins gained national recognition for his work in improving steam boilers and other apparatus, and had to his credit a total of 81 inventions.

He was born in Ballston Spa, N. Y., on August 20, 1857, and received his education in public and private schools. Before locating in Roselle he lived for several years in Glascow, Scotland, where he conducted experimental work for the Babcock & Wilcox Co. He joined that company in 1881 in charge of the erecting department and was a member of its Board of Directors at the time of his death.

Mr. Higgins became a member of the A.S.M.E. in 1893. He was also a member of the American Society of Naval Engineers, New York Flute Club, Roselle Golf Club, and the Harvard Club of Roselle. He had resided in Roselle for thirty years and had been a member of the Borough Council and Board of Health, and a trustee and church master of the First Presbyterian Church there. He was a frequent contributor to charitable organizations. He is survived by his widow, Ella R. Higgins.

JAMES HOGG

James Hogg, a member of the A.S.M.E. since 1913, died at Amsterdam, N. Y., where he was consulting engineer and wool expert for Stephen Sanford & Sons, Inc., on December 31, 1930.

Mr. Hogg was born at Rawdon, England, on November 10, 1851. Following a common school education he spent about twelve years in England learning the woolen and worsted manufacturing business.

In 1880, Mr. Hogg came to the United States where he secured employment as overseer at the Globe Worsted Mill, Lawrence, Mass. He remained there until 1888, during which time he developed an improved slide rule.

Mr. Hogg's first association with Stephen Sanford & Sons was in 1888. He served the company as superintendent until 1906, largely employed in machinery and power construction work. From then until 1913 he held a similar position with the Bigelow Carpet Company at Lowell, Mass., and did consulting work on machinery and power problems. He returned to Amsterdam in 1913. He is survived by his widow, four sons, and two daughters.

HENRY HOLGATE

Henry Holgate, consulting engineer, Montreal, Quebec, Canada, died on January 21, 1930.

Mr. Holgate was born at Milton, Ontario, on September 14, 1863, the son of John and Jane (Browne) Holgate. He attended grammar and high school in Toronto, after which he served an apprenticeship to the Northern Railway of Canada. For five years following the completion of his training he was employed by that railway as chief assistant engineer, and retained that position for four years with the Grand Trunk Railway, into which the Northern Railway was merged in 1888.

During the years from 1892 to 1901 Mr. Holgate was connected successfully with the Central Bridge Works as engineer; engineer in charge of construction and plant for the Royal Electric Company of Montreal; and manager and engineer of the suburban electric railways of Montreal and of the West India Electric Company of Jamaica, for which he built a hydroelectric and long-distance transmission system.

From this time until his death Mr. Holgate was identified with hydroelectric work. For ten years, in partnership with R. A. Ross, he engaged in general hydroelectric engineering practice. Since 1911 he had practiced independently. His projects included the Cedar Rapids Power development, which entailed the design and construction of hydroelectric plants and the dam on the Spanish River at Big Eddy and he served as president of the Cedar Rapids Power Company in 1911. He was vice-president of the Bridge River Power Company, Ltd., of British Columbia, and consulting engineer to the Province of New Brunswick. He served as chairman of the Royal Commission to investigate the collapse of the Quebec bridge in 1907, and was one of a government commission to advise on the expansion of the Montreal harbor. He was director of the Canada Grip Metal Company and managing director of the Serge Island Estates, Ltd. The last important work undertaken by Mr. Holgate was an exhaustive study of and report on the proposed St. Lawrence deep waterway, which he carried out in association with J. A. Jamieson, of Montreal, at the request of the Montreal Board of Trade.

Mr. Holgate became a member of the A.S.M.E. in 1921. He also belonged to the American Society of Civil Engineers and the Engineering Institute of Canada, which he had served as councillor and vice-president, was president of the Engineers Club of Montreal, and a member of the board of management of the Montreal General Hospital.

Surviving Mr. Holgate are his widow, formerly Bessie Bell Headley, whom he married in 1888, and two sons, Henry W. and Edwin H. Holgate.

IRA NELSON HOLLIS

"Ira Nelson Hollis has lived that others might live better." These words, first printed nine years ago in their class book by seniors at Worcester Polytechnic Insitute, of which he was then the president, aptly epitomize the character of the distinguished engineer and educator who died at his home in Cambridge, Mass, on August 15, 1930. His career, begun with nineteen years of service in the United States Navy, and continued through twenty years as professor of engineering at Harvard University, reached its culmination in the presidency of the Worcester Polytechnic Institute, which he held from 1913 to 1925. During the year 1916-1917 he was also president of The American Society of Mechanical Engineers, of which he had been a member since 1884. On resigning the presidency of the Worcester engineering college because of failing health, he was elected by special action of the trustees to the honorary office of president emeritus. He returned to Cambridge, where he established a home at 985 Memorial Drive. His closing years were happily occupied with occasional travel, lecturing, and writing, and in the serene enjoyment of his books, his friendships, and rich memories. He is survived by four children, Janette R., Oliver Nelson, Elinor V.,

and Carolyn. His wife, who was Miss Caroline Lorman, of Detroit, died several years ago.

Dr. Hollis was the recipient of many academic honors, among them being the degrees of A.M. from Harvard University, L.H.D. from Union College, Sc.D., from the University of Pittsburgh, and D.Eng. from the Worcester Polytechnic Institute. He was a fellow of the American Society of Arts and Sciences, and a member of numerous scientific and engineering societies.

As president of The American Society of Mechanical Engineers, Dr. Hollis, at enormous expenditure of time and energy, visited in person nearly every Local Section of the Society, exemplifying thereby an ideal of service that has been a lofty challenge to his successors in that office. At the meetings of the Society he was always the central figure, constantly surrounded by hosts of fellow-members, who were drawn to him less by his official position than by his strong and appealing personality. For some years, both before and after his term of office, he served on the Council, and for a time was chairman of the important Committee of Awards, which position he resigned at the last Annual Meeting. He was made an Honorary Member of the Society in 1928.

He was born at Mooresville, Indiana, on March 7, 1856. His parents were in such straightened circumstances that the boy was often sent to gather driftwood along the bank of the Ohio river to keep the home fires burning. He received his early education in the public schools of Louisville, Ky., and at an early age went to work in the railroad offices there. At this time he chanced to hear of an examination which was shortly to be given at Annapolis for admission to the Naval Academy, and determined to try for acceptance. As his preparation in some of the required subjects had been insufficient, he borrowed a number of books on mathematics, and resolutely set himself to master them. He had no money to defray the expenses of the journey East, but as an employee of the railroad was able to secure a pass. He took the examinations, received the highest rank of any of the 125 candidates, and was admitted to the Academy along with twenty-four others. He maintained first place throughout his course, and was graduated at the head of his class.

Assigned to the Engineering Corps, he was commissioned an assistant engineer in 1880, and a passed assistant engineer in 1888. One of his memorable experiences at sea was the chase of the filibuster *Itata* by the U.S.S. *Charleston*, the flagship of the Pacific Squadron, on which he was then the chief engineer. For his service on this occasion he was officially commended to the Navy Department by Admiral McCann. During his naval career he was detailed for a time as professor of marine engineering at Union College. Following his work at the college he became a member of the Advisory Board which built the White Squadron. During the summer of 1892 he delivered at the Naval War College a course of lectures on "The Ships of Our Modern Navy," and these lectures were afterward issued to the service in book form.

His brilliant reputation as an engineer in the Navy was recognized by Harvard University in 1893, when he was offered the position of professor of engineering in that institution. He thereupon resigned from the Navy, and devoted the rest of his life chiefly to the cause of engineering education.

At Harvard he at once manifested unusual abilities as a teacher. He remodeled and greatly developed the department of engineering, and became an outstanding figure in the Harvard faculty. He was chairman of the athletic committee for several years, and it was under him that the Harvard Stadium was erected. His services were not entirely lost to the Navy, however, as in 1898 he was associated with Rear Admiral Wainwright in the reorganization of the personnel of the Navy, and the bill written by them was used as a basis for action in Congress. He also served twice on the board of visitors at the Naval Academy.

In 1913, after twenty years of teaching at Harvard, Professor Hollis was called to the presidency of the Worcester Polytechnic Institute. It was characteristic of the modest and retiring disposition of the man that he refused to sanction any public and formal exercises of inauguration, but, on July 1 of that year, quietly took up the duties of his office.

Soon after he arrived at the Institute he was called to face one of the severest crises that have confronted the college. The withdrawal of financial aid from the state left many of the colleges of the commonwealth, the Worcester Polytechnic Institute among them, in serious straits. President Hollis met the situation with courage, wisdom, and rare skill, and successfully piloted the Institute through the perils of inadequate finance to a sound and secure position among the engineering colleges of the country. A little later the Institute, along with other colleges, was plunged into new and distressing, if less critical, difficulties on the entrance of the United States into the World War. Only those who were then responsible for the safe conduct of the institutions of higher learning through a period when the students became soldiers, and responsibility was shared in strange and curious ways between the military officers and the officers of instruction, can adequately realize the delicacies and difficulties of the situation. Again Dr. Hollis was equal to the emergency. Through diplomacy and tact he succeeded in affording complete cooperation with the Government, while still insisting on maintaining sound scholastic standards. At the same time new financial problems were encountered in the necessity of advancing salaries to keep pace with the growing cost of living; and in the solving of these problems President Hollis was also eminently successful.

During his administration the Institute celebrated its fiftieth anniversary with elaborate ceremonies, participated in by representatives of the leading educational institutions of the country. On this occasion the corner stone of the alumni gymnasium was laid, thus opening a new era of athletic progress at the Institute, in the advancement of which President Hollis played a conspicuous part. It was under him, too, that the Tech Council was established, and won for itself an important role in governing student life and activities.

But great as were the achievements that have been enumerated, one even greater remains to be mentioned. "It was not long after his arrival," wrote the seniors of 1916 in their class book, "before we learned that the Office . . . .was to be a place where our difficulties could be cleared up. We had only to state the extent of these, and 'Prexy' could immediately find a way out of them. Through his energy a change was made in the attitude of the upper classmen toward the freshmen. Class rushes were abolished; freshman rules were toned down; and many other changes made to increase the kindly feeling between classes. In his heart he had the welfare of every student; a kindly word of encouragement to the disheartened, or a well-meant reproof to the backward student, was all that was needed to point out the way he should go." The marked simplicity of his manner, the kindly sympathy of his speech, and his evident sincerity commanded the confidence and loyalty of the students, while their admiring respect was captured and held by his lofty attainments. The example he afforded them of real greatness combined with modesty of bearing and zealous will to serve, have left an ineffaceable impression upon the characters of them all.

Upon these engineering students, immersed in the pursuit of science, and often boasting their materialistic tendencies, President Hollis gained his commanding influence by the steadfast manifestation of a lofty idealism. His closing words in delivering the commencement address on the year of his coming to the Institute are an eloquent expression of the deeper philosophy of his life. "It seems to me," he said, "that we are on the entrance to a great moral and religious growth. Man is completely freed from his material environment by steam and water power, and he will grow rapidly into that faith and love which will solve most of our problems, if only he does not turn back. Let us not be led away by that common objection raised among self-styled practical people against all ideals, 'Oh, that would be the millenium.' Is the millenium the false fire that hovers over marshy ground, and that precedes us and vanishes as we are engulfed? Is it not rather the hope and goal of mankind, made possible and even probable by the proper use of man's time? I must believe that in this new freedom our descendants will gain a spiritual faculty over and beyond reason, that will teach them to follow and to understand instinctively the law of Christ given to us as the result of his ripe experience of life. When the lawyer asked him, 'Master, which is the great commandment in the law?' He replied, 'Thou shalt love the Lord, thy God, with all thy heart and with all thy soul and with all thy mind; this is the first and great commandment; and the second is like unto it: 'Thou shalt love thy neighbor as thyself. On these two commandments hang all the law and the prophets.' If the race comes to the practice of these two commandments as law, it will deserve the earth, and national, social, and industrial problems will dissolve in man's highest happiness. They are, in reality and truth, all the law and the prophets. Follow them as men, and you cannot fail to inherit the earth."

It was in the spirit of this philosophy that President Hollis devoted his life to the service of his students and his fellow-men. But his service was never limited to the individual: it was always freely extended to the collected individuals that make up the State. In his speech accepting the presidency of The American Society of Mechanical Engineers he urged his hearers to regard their work as an obligatory service of the state. "That," he said, "is our motto, and that is what we must strive toward during the coming year and all time as we must pass on into the higher atmosphere of goodwill, service, and cooperation."

CHARLES J. ADAMS.[1]

[1] Professor of English, Worcester Polytechnic Institute, Worcester, Mass.; prepared in cooperation with Ralph Earle, president, and Charles M. Allen, professor of hydraulic engineering of the Institute.

EDWARD ISAIAH HACKER HOWELL

Edward Isaiah Hacker Howell, retired, died on November 2, 1930, in Philadelphia, Pa. He was born in Philadelphia on October 20, 1843, the son of William and Rebecca (Hacker) Howell. He received his education at the Germantown Academy, the Eagle's Wood School, Perth Amboy, N. J., and the Polytechnic College of the State of Pennsylvania, which gave him the degrees of M.E. in 1862, and M.M.E. in 1866.

After serving an apprenticeship with Reaney Archibald & Co., Chester, Pa., and I. P. Morris & Co., Philadelphia, he worked in the drawing room and as assistant superintendent for W. B. Le Van, of Philadelphia, on steam engines, pumps, governors, and elevators, and in general practice connected with steam and hydraulic machinery until 1874, when health and eyesight necessitated his retirement. He served in the Civil War in the Germantown Home Guard.

Mr. Howell became a member of the A.S.M.E. in 1889, was one of the founders of the Geographical Society of Philadelphia, and a member of the Historical Society of Pennsylvania and the Historical Society of Germantown. He also belonged to the Colonial Club, the Art Club of Philadelphia, and the Germantown Unitarian Society, and he was a founder of both the Science and Arts Club of Germantown and the Ausable Club of New York. These memberships indicate his interest in historical organizations, art and music, and forest preservation, as well as engineering.

ALLEN HUBBARD

Allen Hubbard, member of the Boston consulting engineering firm of Hollis French and Allen Hubbard, died on December 14, 1930, at the Newton Hospital, from a hemorrhage. He was born in Westfield, Mass., on December 9, 1860, the son of George and Clara (Edy) Hubbard. He was educated in the Westfield schools and at Sheffield Scientific School, Yale University, from which he was graduated with the degree of Ph.B. in 1883. After some early experience as draftsman and engineer with two Providence firms, the Riverside & Oswego Woolen Mills and the H. B. Smith Co., he went to Boston where he was employed for some years by Albert B. Franklin, steam heating contractor. He had been a member of the Hollis French and Allen Hubbard firm since 1898.

Mr. Hubbard devoted himself to consulting work connected with the design of steam power plants, heating and ventilating systems, mill work and general consultation. Yale, Harvard, Wellesley, Mount Holyoke, William and Mary, and other educational institutions engaged his services in their building programs, and he also served as consulting engineer on the construction of the Boston Opera House, the Art Museum, Public Library, and other public and business buildings in Boston.

He was director of the Exolon Company and president of the Wm. L. Gilbert Clock Co.

In addition to the A.S.M.E., of which he had been a member since 1910, Mr. Hubbard held membership in the American Society of Heating and Ventilating Engineers and the American Institute of Consulting Engineers, and at one time was chairman of the Affiliated Technical Societies of Boston. He belonged to a number of clubs, including the Engineers, Yale, University, and Exchange of Boston, and the Charles River Country Club, for the beauty of the development of which he was largely responsible. He was a vestryman of the Trinity Episcopal Church at Newton Centre, Mass.

Surviving Mr. Hubbard are his widow, formerly Edna L. Woodruff, whom he married in 1896, and two sons, Allen Hubbard, Jr., and Gilbert Hubbard.

CHARLES TRIPLER HUTCHINSON

Charles Tripler Hutchinson, president and general manager of the McGraw-Hill Company of California, editorial director of *Electrical West*, died on February 12, 1930, at Oakland, Calif.

Mr. Hutchinson was born in San Francisco on January 31, 1876, the son of Frederick Winslow and Ellen Cass (Tripler) Hutchinson. He received his education in the Boys' High School and the Commercial High School in San Francisco and through the International Correspondence School. He began professional work in 1894 with the Union Iron Works in San Francisco, and advanced through various positions to that of general manager of the mining machinery department. He was responsible for the design, construction, and erection of equipment for metal mines, as well as sales of such equipment. In 1907 he took a similar position with the Joshua Hendy Iron Works of San Francisco. He entered the technical publishing field in 1912 as editor of *Western Engineering* and was also editor of *Metal Trades*. In 1915 he became vice-president and general manager of the Dewey Publishing Company, San Francisco publishers of *Mining and Scientific Press*, *Western Engineering*, and *Metal Trades*. He joined the McGraw-Hill Publishing Company in 1922, at which time the *Mining and Scientific Press* was purchased by them. They were already publishing the *Journal of Electricity*, which later grew into *Electrical West*.

Mr. Hutchinson wrote many articles for the technical press and was a contributor to McFarren's "Stamp Milling" and to Janin's "Mining Engineers' Handbook." He also designed improvements in automatic ore feeders, rock breakers, and stamp mills. He was a member of the Jury of Awards of the Department of Mining and Metallury of the Panama-Pacific International Exposition in 1915, and was awarded a medal for his services to the mining and metallurgical exhibit of the Exposition. He became a member of the A.S.M.E. in 1910, was secretary of its San Francisco Section in 1913-1914, and represented the Society on the Board of Managers of the 1915 International Engineering Congress. He was also a member and past-president of the Engineers Club of San Francisco and the San Francisco Electrical Development League; a member since 1923 of the Executive Committee of the Pacific Coast Electrical Association; and chairman since 1925 of the Advisory Committee of the California Electrical Bureau. He was a member of the Masonic order and also belonged to the Bohemian Club and Commonwealth Club of San Francisco, the Claremont Country Club of Oakland, Mt. Diablo Country Club of Diablo, and the Sons of the American Revolution. He married Gertrude Allen in 1907, and is survived by her.

E. A. W. JEFFERIES

E. A. W. Jefferies, whose death occurred in Worcester, Mass., on October 20, 1930, was born in Malmsbury, England, on February 23, 1862, the son of John and Sarah Grayel Jefferies. He received his technical education at University College, London, and served an apprenticeship and worked in the drafting room of Fielding & Platt, London, from 1877 to 1880. He then spent a year as draftsman for R. H. Tweddell, London, and returned to Fielding & Platt in 1882 as assistant superintendent.

Mr. Jefferies came to the United States in 1883 to become chief draftsman for the Morgan Engineering Company at Alliance, Ohio. After advancing to the position of chief engineer he became associated with the R. D. Wood Company of Philadelphia, Pa., with which company he first became interested in the development of producer gas machines. He spent the greater part of his life in this field and was recognized as an authority on both the theory and practice of making producer gas. At the time of his death he was head of the Gas Producer Department of the Morgan Construction Company of Worcester, Mass., which position he had filled since 1904.

Mr. Jefferies became a member of the A.S.M.E. in 1892. He is survived by his second wife, and by two daughters and a son, Mrs. Jerome R. George, Mrs. Arthur D. Sykes, and Ernest Smith Jefferies.

PETER JUNKERSFELD

Colonel Peter Junkersfeld, vice-president of the Stone & Webster Engineering Corp., died suddenly at his home in Scarsdale, N. Y., on March 18, 1930.

Colonel Junkersfeld was born in Sadorus, Ill., on October 17, 1869, the son of Peter Joseph and Mary Josephine (Schmitz) Junkersfeld. He attended the Champaign, Ill., High School, and Northern Indiana Normal School, at Valparaiso, and was graduated from the University of Illinois in 1895, with a B.S. degree. In 1907 the degree of E.E. was conferred upon him by that institution.

After a few months with the Fred W. Wolf Co., Chicago, as draftsman on refrigerating machinery, he became connected with the Chicago Edison Company. He remained with this company and its successor, the Commonwealth Edison Company, for nearly 24 years. He began as an assistant in the power plant and at the time of his resignation in 1919 was assistant vice-president.

In 1916 Mr. Junkersfeld was elected president of the Association of Edison Illuminating Companies. Following his resignation from the Commonwealth Edison Company Colonel Junkersfeld was associated with the Division of Construction and Engineering of Stone & Webster, Inc., until 1922, when he became a member of McClellan & Junkersfeld, Inc., engineers and constructors. In 1928 this firm was merged with the Division of Construction and Engineering of Stone & Webster, Inc., to form the Stone & Webster Engineering Corporation, of which Colonel Junkersfeld was appointed a vice-president.

In 1916, Josephus Daniels, then Secretary of the Navy, appointed Mr. Junkersfeld to the Naval Consulting Board as an associate member. He entered the U. S. Army, Construction Division, as a Major in the Engineers Reserve Corps in 1917, rose to the rank of Colonel, and was actively engaged in building cantonments,

camps, hospitals, port terminals, warehouses, and munition plants. In 1919 he was awarded the Distinguished Service Medal by Newton D. Baker, then Secretary of War.

Colonel Junkersfeld was a past vice-president of the American Institute of Electrical Engineers, was the first president of the Construction Division Association and a past vice-president of the Western Society of Engineers. He became a member of the A.S.M.E. in 1910 and also belonged to the American Society of Civil Engineers and the Franklin Institute. His clubs included the Engineers (New York and Chicago), Lawyers (New York), Western Universities Club of New York, and Scarsdale Golf Club.

His widow, Mrs. Anna C. (Boyle) Junkersfeld, whom he married in 1901, and two daughters, Florence Rita and Mary Josephine Junkersfeld, survive him.

WILLIAM CONRAD KOCH

William Conrad Koch, since 1918 vice-president, treasurer, and general manager of the Twin City Brick Company, St. Paul, Minn., died on December 10, 1930, at the Miller Hospital in that city after an illness of several weeks. He was born in Geneseo, Ill., on October 30, 1889, but spent the most of his life at St. Paul. After attending high school there he entered Harvard University, from which he received the degree of S.B. in 1913. He spent the following year at the Harvard School of Business Administration and then took a position as assistant superintendent of the Twin City Brick Company.

During the Mexican border troubles in 1916 he served with Battery D of the Minnesota National Guard. In 1917-1918 he was chairman of the Minnesota State War Inventions and Research Committee by appointment of the governor, and also was a member of the United States War Industries Board, Washington, D. C., in 1918.

In his work with the Twin City Brick Company Mr. Koch was in charge of operations and construction of two plants at St. Paul, two at Des Moines, and one at Red Wing, Minn.

Mr. Koch was keenly interested in general business conditions. He attended the National Business Survey Conference held at Washington the winter preceding his death under the auspices of the U. S. Chamber of Commerce, and had but recently returned from a business leaders' tour sponsored by the National Research Council.

He became a member of the A.S.M.E. in 1927, and also belonged to the American Society for Testing Materials, American Ceramic Society, and the St. Paul Engineers Society. His term as president of the American Face Brick Association expired shortly before his death. He was the youngest man ever to have held that office. He was a former secretary of the St. Paul Institute, commodore of the White Bear Yacht Club and was active in the St. Paul Association and United Improvement Council. He was a member of the Minnesota Club and the University Club.

In 1919 he married Margaret Paine of Cambridge, Mass. Surviving him are his widow and four children, Mary Adams, William C., Jr., James L. P., and Frederick Karel Koch.

EMIL KWARTZ

Emil Kwartz, designing and consulting engineer of Seattle, Wash., died at the home of his sister, Emma O. Kwartz, in Los Angeles, Calif., on November 28, 1930. A brother, Ernest G. Kwartz, in Oakland, Calif., also survives him. He was unmarried.

Mr. Kwartz was born at Westmanland, Sweden, on September 29, 1876, and was graduated in 1898 from the four-year course in mechanical engineering at the Stockholm technical school. He came to the United States in 1900, after several years' experience in diamond drilling in Swedish mines, electrical drafting for Luth & Rosen, in Stockholm, and erecting buildings and machinery at the World's Fair in France in 1899-1900. His work in this country, beginning as mechanical draftsman for the Western Electric Company in Chicago, gave him experience on a variety of machinery, including machine tools and railway specialities for the Railway Appliance Company, Chicago; presses and dies for E. W. Bliss Co., Brooklyn, N. Y.; experimental machinery for the Mergenthaler Linotype Company, Brooklyn; tools for the E. M. F. Auto Co., Detroit, Mich.; and plasterboard manufacturing machinery for the Gypsum Products Corporation in Seattle. He also engaged in structural drafting for the J. B. & J. M. Cornell Co., New York, and plant layout work for the Duplex Metals Company, Chester, Pa., in 1907, and was sales engineer for the Jacobsen Engine Company of Chester for a time.

From 1910 to 1915 Mr. Kwartz was located at Chicago, devoting his time to machine and die design. During this period he invented a large machine for cutting off cardboard tubes of from two to six inches diameter for paper cans. He also designed a voting machine and all of the dies, etc., for producing its parts, and a special press and dies for the manufacture of hose clamps.

Mr. Kwartz went to Seattle in 1915. His work there included inspection of heavy oil engines; a power house addition for the Tacoma Smelting Company; a continuous oil press for the Sea Products Company; and machinery for the Bemis Bros. Bag Co. His death resulted from burns suffered while designing machinery for the Puget Sound & Alaska Powder Co.

Mr. Kwartz had been a member of the A.S.M.E. since 1925.

EDWARD POWELL LEWIS

Edward Powell Lewis, managing director of Messrs. Geo. W. Kelly & Lewis Pottery, Ltd., of Spring Vale, Victoria, Australia, who for some years had been in ill health, died on January 10, 1930. He was born at Heidelberg near Melbourne, on July 24, 1863. At the age of 17 he was indentured with the engineering firm of Wright & Edwards, at Melbourne. After a five-year apprenticeship he entered the drawing office of that company, where he remained until 1892, being promoted to the position of head draftsman and assistant manager. During this time he designed mill engines and was responsible for the designing and construction of a large portion of the street cable plant for the City of Melbourne. As there were no public technical institutions in Victoria he supplemented his practical experience during these years by private tuition and study.

In 1892 Mr. Lewis was appointed works manager and superintendent for Messrs. Thompson & Co. of Castlemaine, Australia, a position which he retained for about seven years. He was responsible for the design and construction of pumping plants for town water supplies and designed numerous high-pressure boilers, among which were those for the Melbourne metropolitan sewerage pumping plant. He was also responsible for the design of the large gate valves (88-in. diameter) used for the rising mains at that plant, as well as steam winding plants, two-stage air compressors, Corliss engines, and surface and jet condensing plants.

About thirty years ago he entered into partnership with the late Mr. Geo. W. Kelly of Melbourne, and the firms name became Geo. W. Kelly & Lewis. Modern tools and equipment were installed and the company engaged in the design and construction of general machinery covering a very wide range and including mining, milling, and pumping equipment. On the death of Mr. Kelly the business was absorbed by Mr. Lewis and his sons. Increasing business and the congestion within the city area eventually led to the erection of a new plant at Spring Vale, about sixteen miles from Melbourne. The business will be carried on by his two surviving sons.

Mr. Lewis became a member of the A.S.M.E. in 1919.

WILLIAM LINDHORST

William Lindhorst, consulting engineer for the Semet-Solvay Engineering Corporation, New York, N. Y., died on January 12, 1930. He was born in Brunswick, Germany, on September 21, 1877, the son of William August and Friederike (Reinhart) Lindhorst. He attended Hanover College, Hanover, Germany, where he received the degree of M.E.

In 1900 Mr. Lindhorst became assistant erecting engineer for the Brunswick Machine Company, and during three years with this company assisted in the erection of beet sugar factories and refineries in Germany, Italy, and Russia. In 1903 he joined the Novelty Steam Boiler & Construction Co., Brooklyn, N. Y., as draftsman and designer of steam boiler chemical apparatus, gas and by-product apparatus, and copper furnace plants. He became connected with the Semet-Solvay Engineering Corporation, a division of the Allied Chemical & Dye Corp., in 1912, being located first at the Solvay, N. Y., office and later in New York.

Mr. Lindhorst became a member of the A.S.M.E. in 1922. He was also a Mason and a Presbyterian. He married Gertrude Helen Egerland, who, together with two daughters, Florence and Gertrude Lindhorst, survive him.

EDWIN HOYT LOCKWOOD

Edwin Hoyt Lockwood, Higgins professor of mechanical engineering at Sheffield Scientific School, Yale University, died on April 16, 1930, at the New Haven Hospital, Conn., of heart disease. He was born on October 31, 1866, at New Canaan, Conn., the son of Samuel Kellogg and Mary (Hoyt) Lockwood. He received his early education in the public schools of New Canaan and at the New Canaan Seminary and was graduated from the Sheffield Scientific School in 1888 with the degree of Ph.B.

After a year as mechanical draftsman of special machinery for the Diamond Match Co. he returned to Yale for further study and be-

came an instructor in mechanical drawing. During the summer of 1895 he secured practical experience as draftsman at the Southwark Foundry, Philadelphia, and he worked in a similar capacity for the Deane Steam Pump Company, at Holyoke, Mass., in the summer of 1900.

In the latter year he was made an assistant professor of mechanical engineering and in 1924 an associate professor. In 1927 he was appointed Higgins professor of mechanical engineering. He was given the degrees of M.E. in 1892 and Ph.D. in 1901. During his long career on the Yale faculty Professor Lockwood taught nearly every subject in mechanical engineering and had become known throughout the country for his important investigations on fuel combustion in power and heating and in automotive engineering. In 1928 he completed experiments in the use of exhaust gases to increase automobile mileage and had done much other research work. He took an important part in planning the Mason Laboratory and Winchester Hall at Yale, and was the author of papers on automobile engineering and heating and ventilation.

Professor Lockwood was affiliated with many engineering societies. He joined the A.S.M.E. as a junior member in 1890 and was promoted to full membership in 1903. He was also a member of the Connecticut Academy of Arts and Sciences, the Society for the Promotion of Engineering Education, the Society of Automotive Engineers, the Society of Heating and Ventilating Engineers, and the Yale Engineering Association. He was a fellow of the American Association for the Advancement of Science.

In 1900 he married Elizabeth Pendleton, who, together with a son, Edward H. Lockwood, Jr., and a daughter, Mrs. Elizabeth P. Parker, survive him.

HENRY NICHOLAS LONG

Henry Nicholas Long, chief engineer of The Viscose Company, Parkersburg, W. Va., died in the Johns Hopkins Hospital, Baltimore, Md., on May 5, 1930. He was born in Deal, England, on November 27, 1879, the son of John and Elizabeth (White) Long. His education was received at the Brooklyn Technical and Trade School.

His professional experience began in 1894 as marine engineer apprentice at Glasgow, Scotland, and later he served several years at sea as engineer's apprentice. In 1901 he entered the British Navy as Junior Engineer, and in 1907 he became connected with the assembling department of the General Electric Company, Lynn, Mass. For two years he worked on general construction for the Edison Company, Brooklyn, N. Y. From 1910 to 1916 he engaged in the erection and installation of mechanical equipment in various cities throughout the United States. He then joined The Viscose Company as erecting engineer at Roanoke, Va. He was appointed chief engineer of the company in 1926, to build and equip the plant at Parkersburg. This work involved problems in refrigeration, steam circulation, water softening, sewage disposal, power production, etc.

Mr. Long was the inventor of a ratchet pipe wrench and was Corporal of the National Guards at Roanoke, Va. He became a member of the A.S.M.E. in 1928. He was also a member of the Masonic fraternity and the Elks. He was an Episcopalian. He married Annie Pearl Griffin in 1917, and is survived by her.

FREDERICK GUNARD LUNDGREN

Frederick Gunard Lundgren, assistant chief engineer for the American Dressler Tunnel Kilns, Inc., Cleveland, Ohio, died of pneumonia, on April 16, 1930, in that city. He was born at Kalmar, Sweden, on June 1, 1894, and received his education at the University of Illinois, where he obtained the degree of B.S. in 1915, and later the degree of M.E.

His professional experience began in 1903 with the Mills Novelty Company, Chicago, Ill. In 1907 he joined the Pope Manufacturing Company, Chicago, Ill., and was engaged in estimating and systematizing the manufacture of bicycles and automobiles. He also did similar work for the Orr & Lockett Hardware Company, Chicago, Ill., from 1908 to 1911.

Following his graduation from the University of Illinois he was employed by the American Car and Foundry Company, at Terre Haute, Ind., Milton, Pa., and Detroit, Mich., the Grasselli Chemical Company, Grasselli, N. J.; and the Ford Motor Company, Detroit. He designed and supervised the construction of factory and mill buildings and power plants, and built many special devices for performing mechanical work quickly and economically. In 1920 he became a partner with Lundgren and Deardorf, general contractors and engineers, Terre Haute, Ind., with which he remained until he joined the American Dressler Tunnel Kilns, Inc., in 1929.

Mr. Lundgren became an associate member of the A.S.M.E. in 1916 and a member in 1922.

DONALD DWIGHT LYNCH

Donald Dwight Lynch, research assistant, Technical Research Department, International Combustion Engineering Corporation, Newark, N. J., died on April 26, 1930. He was born at Oakland, Iowa, on January 22, 1899, and received a B.S. degree in mechanical engineering from the University of Nebraska in 1925. He remained at the university for about a year, conducting experimental tests on insulation at low temperatures, and then accepted a position with the International Combustion Engineering Corporation, in its New York office. He was transferred to the Newark office shortly before his death.

Mr. Lynch became a junior member of the A.S.M.E. in 1926.

RUDOLPH EDWARD LYON

Rudolph Edward Lyon, whose death occurred on February 28, 1930, was born at Ogden, Utah, on July 20, 1905. He attended the University of Utah, completing his work there in 1927. He then became connected with the Westinghouse Elec. & Mfg. Co., at East Pittsburgh, Pa., as a graduate student, and at the time of his death was one of its student salesmen.

Mr. Lyon became a junior member of the A.S.M.E. in 1928.

DONALD MacARTHUR

Donald MacArthur, vice-president and director of the Koppers Gas & Coke Co., and an officer of many other subsidiaries of the Koppers Company, died at the Mountainside Hospital, Montclair, N. J., on July 24, 1930, following an operation. He was born in Glasgow, Scotland, on August 30, 1880, the son of Angus and Mary (MacAlpin) MacArthur. He received his education at the Superior High School, Superior, Wis., and at the University of Wisconsin, where he was graduated with the degree of B.S. in Mechanical Engineering in 1904.

Mr. MacArthur's professional experience began after graduation with the Laclede Gas Light Company of St. Louis, Mo., where he was engaged in the design of station gas meters, and later was superintendent of the gas plant for this company. This latter position included the supervision of operation of all the company's manufacturing stations, making coal gas, water gas, and Pintsch gas. In 1916 he became connected with The Koppers Company as manager of the Seaboard By-Product Coke Company in charge of engineering at the Jersey City coke oven plant. He also did work in connection with light-oil and distillation plants in various cities. He became vice-president of the Seaboard By-Product Company in 1928 and vice-president and director of the Koppers Gas & Coke Co. in 1929.

Mr. MacArthur became a member of the A.S.M.E. in 1918. He was also a member of the Society of Gas Lighting. His club memberships included the Glen Ridge Country Club and Newark Athletic Club. He was an elder in the Central Presbyterian Church, Montclair, N. J., and a member of the Boy Scout Council of Glen Ridge, N. J. In 1905 he married Georgia Jane Doey, and she, together with a son, Donald MacArthur, survive him.

FRANCIS MacLEHOSE

Francis MacLehose, superintendent of the Waterside Stations of the New York Edison Company, died on November 17, 1930. He was born at East Orange, N. J., on September 13, 1885. His education was received in the East Orange schools, Stevens Preparatory School, and Stevens Institute of Technology, which awarded him the degree of M.E. in 1906.

His professional experience began with work for the New York Edison Company, as substation operator, in which capacity he served until 1908, when he was promoted to the position of central station operator. In 1910 he became assistant electrical foreman at the Waterside Station and in 1913 was "loaned" as superintendent of the Hales Bar Power Station of the Chattanooga & Tennessee River Power Co. He returned to New York two years later as assistant superintendent at the Waterside Station. His promotion to superintendent of Stations Nos. 1 and 2 came early in 1926.

He became a member of the A.S.M.E. in 1920, and was also a member of the American Institute of Electrical Engineers, the New York Electrical Society, the National Electric Light Association, and the Canadian Club. He was unmarried.

HERMAN H. MANGELS

Herman H. Mangels, engineer for the United Light & Power Engineering & Construction Co., Kansas City, Mo., was killed in an automobile accident near Denver, Colo., on September 7, 1930,

when returning from a vacation trip. He was the son of Mr. and Mrs. Ben Mangels of Davenport, Iowa, and was born there on June 9, 1896. He attended the Chicago Technical College and after two years as draftsman with the Tri-City Railway & Light Co., of Davenport, began work in a similar capacity with the United Light & Power Co. He was promoted to the head of the drafting department after a few years, and later was transferred to the construction department as a superintendent. His first project was a concrete dam at Coralville, Iowa, after which he built power plants for the company at Fort Dodge and Davenport, Iowa, and at Columbus, Ohio. Mr. Mangels returned to the Davenport offices for a time, but in 1927 was put in charge of the Kansas City office.

Mr. Mangels became a member of the A.S.M.E. in 1929 and was active in the Kansas City Section of the Society. In 1917 he married Ruth Hokinson of Moline, Ill., who, together with one son, Warren, survive him.

JOHN A. MARCATO

John A. Marcato, who had become a member of the A.S.M.E. early in 1930, died of heart disease at his home in New York on June 25.

Mr. Marcato was born in New York on August 23, 1880. He supplemented his public school education with private tuition, and at the age of 23 became assistant engineer for the Marcato Elevator Company. After three years he was made chief engineer of the company, and retained that position until his death. For several years he was associated in a similar capacity with the Alloy Metal Wire Company, and during the last ten years of his life he did consulting work, made reports and appraisals, and gave expert testimony in regard to elevators and hoisting equipment.

Mr. Marcato belonged to the Knights of Columbus and Elks, and was an active member of the Holy Trinity Roman Catholic Church. He was very much interested in the political life of Alfred E. Smith and had stumped for him many times in his campaigns.

Surviving Mr. Marcato are his widow, Kathleen G. (King) Marcato, whom he married in 1907, and five children, Grace, John, Edward, William, and Robert.

WILLIAM GRANT MATHESON

William Grant Matheson was born on August 1, 1848, at Albion Mines, Nova Scotia, the son of Isaac and Hanna Matheson. He received his education at the public schools of Chatham, New Brunswick, and the University of New Brunswick; ill-health, however, prevented him from finishing his college course. After a year in a machine shop in Nova Scotia he went to Scotland where he was apprenticed to Baxter Brothers, Dens Works, Dundee (1868–1870) and R. Napier & Sons, Glasgow (1870-1871). He then returned to Canada and entered the employ of I. Matheson & Co., New Glasgow, N. S., in January, 1872. He became manager of this firm in April, 1874, which position he held until he left in June, 1914, to enter the employ of the Nova Scotia Steel & Coal Co. In 1921 the state of his health compelled his retirement from all active work. He died on September 12, 1930.

Mr. Matheson was greatly interested in regulations for the construction and inspection of steam boilers, having taken a prominent part in the formulation of a uniform set of rules for the provinces of Canada as the representative of Nova Scotia. He also took a keen interest in the work of the A.S.M.E. Boiler Code Committee.

He took an active part in town affairs, particularly the construction of public works, and also in connection with the School Board, on which he served for some years. He was also prominent in church work, having been a member of the Session of Westminster Presbyterian Church since 1900. He had been a member of the A.S.M.E. since 1891, and also belonged to the Engineering Institute of Canada and the Association of Professional Engineers of Nova Scotia.

Besides his widow, Annie Parks Matheson, whom he married in 1902, he leaves a daughter, Hannah Matheson, and two sons, W. Drummond and J. H. Parks Matheson.

FRANK ELLIOTT MATHEWSON

Frank Elliott Mathewson, director of the department of technical-industrial and special-trade education at the Dickinson High School, Jersey City, N. J., died of sudden attack of heart disease on May 13, 1930.

Mr. Mathewson was born in Chicopee Falls, Mass., on October 28, 1869, the son of Henry Stewart and Mary. L. (Bullock) Mathewson. After leaving high school he worked for five years as an apprentice, machinist, and draftsman for the Chicopee Manufacturing Company, in repair work for cotton mills. From 1889 to 1899 he was employed as draftsman and designer for the Lamb Manufacturing Company, makers of Spalding bicycles and gymnasium equipment, at Chicopee Falls.

Mr. Mathewson entered the teaching profession in 1892 as an instructor in mechanical drawing in evening schools in Chicopee and Chicopee Falls. Three years later he was made principal of the evening drafting school at Springfield, Mass. He resigned that position in 1899, when he accepted an instructorship in mechanical drawing and machine shop practice at the Mechanics Arts (subsequently Technical) High School and Evening School of Trades in Springfield. From 1902 to 1908 he was head of the drawing department of that institution.

In 1908 Mr. Mathewson went to Cleveland, Ohio, as assistant principal in charge of all shop work and drawing at the Cleveland Technical High School. He was located there until 1911, when he spent six months as head of the drawing department of Wentworth Institute, in Boston.

Mr. Mathewson entered the Jersey City school system in 1912 when he accepted the position of director of industrial training in the Dickinson High School where he planned and purchased all equipment and organized the courses of study. During the war he was made district educational director of vocational instruction in the War Department committee on education and special training.

On Oct. 6, 1926, he was elevated to the position he was holding at the time of his death.

Mr. Mathewson was the author of a number of books on mechanical drawing. He became a member of the A.S.M.E. in 1913. He had also served the Eastern Arts Association as president, and for the last nine years of his life was its secretary and treasurer, contributing greatly to the development of the Association.

Mr. Mathewson is survived by his widow, Emily L. (Forbes) Mathewson, whom he married in 1892.

RICHARD KIDDER MEADE

Richard Kidder Meade, of Richard K. Meade & Co., Baltimore, Md., died on October 13, 1930. He was born at Charlottesville, Va., on November 28, 1874, the son of Rev. Francis Alexander and Martha B. (Mosby) Meade. He was graduated from the University of Virginia in 1893, and was given the degrees of B.S. in 1899 and honorary M.S. in 1908 by Lafayette College. He was an honorary Phi Beta Kappa.

After a few years' experience as city editor of the *Independent-Herald*, Hinton, W. Va., and as chemist for the Longdale Iron Company, Allegheny Co., Va., Mr. Meade became instructor in chemistry at Lafayette College in 1897. Beginning in 1902 he served successively as chief chemist for the Edison Portland Cement Company, chief chemist and superintendent of the Northampton Portland Cement Company, chief chemist of the Dexter Portland Cement Company, director of the Meade Testing Laboratories, Allentown, Pa., and manager of the Tidewater Portland Cement Company, Baltimore. In 1912 he took up consulting practice in Baltimore, specializing in the design of cement, lime, and plaster plants. He was the founder and first editor of *The Chemical Engineer* and took out many patents and improvements in cement manufacture, processes for waterproofing concrete, and apparatus for drying coal. He designed and built several cement plants, many lime plants, plants for producing potash, carbon dioxide, whiting, clay, and many chemicals. He was the author of the Chemists' Pocket Manual (3d edition), Portland Cement (3d edition), Design and Equipment of Small Chemical Laboratories, The Chemical and Physical Examination of Portland Cement, and Brass and Alloy Analysis (with William B. Price).

He became a member of the A.S.M.E. in 1912 and had served on a subcommittee on cement manufacture. He was also a member and one of the founders of the American Institute of Chemical Engineers, and a member of the American Chemical Society and the American Electrochemical Society. His club membership included the Baltimore Country, Engineers (Baltimore), and Chemists (New York). He belonged to the Episcopal Church and the Sons of the American Revolution.

In 1899 he married Fannie Louise Thomas and she, together with two children, Mrs. Martha Haskins Baughman and Francis Alexander Meade, survive him.

GEORGE EDMUND MERRYWEATHER

George Edmund Merryweather, president of the Motch & Merryweather Machinery Company, died at Cleveland, Ohio, on June 8, 1930. He was born in Cincinnati, Ohio, on August 28, 1872, the son

of George Neave and Ellen L. (Beaman) Merryweather. He received his education at the Massachusetts Institute of Technology, which gave him the degree of B.S. in 1896. He was with the Brown & Sharpe Manufacturing Company of Providence for five years and had charge of the company's exhibit at the Paris Exposition in 1900. He became superintendent of the Overman Automobile Company at Chicopee Falls, Mass., in 1901, and when that company merged with the Locomobile Company of America he became superintendent of the combined firm. In 1904, with Edwin R. Motch, he organized the Motch & Merryweather Machinery Co.

He became a member of the A.S.M.E. in 1903; was an ex-president of the Technology Club of Northern Ohio; and director of the Central United National Bank of Cleveland, the P. A. Geier Company, and the Davenport Machine Tool Company of Rochester, N. Y. He was also a member of the Society of Automotive Engineers; the Engineering Society of Cleveland; the Cleveland Chamber of Commerce; and the University, Union, Mayfield, and Philosophical Clubs in Cleveland.

During the World War he was chief of the machine tool section of the War Industries Board. He held many patents in the machine tool industry.

In 1908 he married Laura Esselborn, who, together with five children, Janet, George E., Constance, Hubert Orr, and Laura Merryweather, survive him.

JOHN HENNON MITCHELL

John Hennon Mitchell, sales manager for the Standard Steel Car Company, central district, with headquarters at Pittsburgh, Pa., died suddenly on January 16, 1930, in New York where he had gone with other officials of his company to attend a convention of the master car builders.

Mr. Mitchell was born in New Brighton, Beaver Co., Pa., August 30, 1872, a son of Joseph F. and Margaret Hennon Mitchell. He was educated in the public schools of Beaver County and studied mechanical engineering at Cornell University. He served as an apprentice for about three years with the Penn Bridge Works at Beaver Falls, Pa., and had two years' experience in the structural engineering department of the Carnegie Steel Co., Ltd., at Pittsburgh, as a designer and estimator. He then entered the motive power department of the Pittsburgh & Lake Erie R. R., at McKees Rocks, Pa., designing locomotives, passenger and freight equipment, shop and road machinery, and making tests of locomotives and materials. He was in complete charge of this work when he left the company to become manager of sales for the Pressed Steel Car Company, in its western district, with headquarters at Chicago. Subsequently he was also appointed sales manager for the Western Steel Car & Foundry Co. After nineteen years in Chicago Mr. Mitchell went to Havana, Cuba, as acting president of the American Steel Company. He returned to this country three years later to become sales manager for the Standard Steel Car Company.

Mr. Mitchell belonged to the Presbyterian Church, Evanston, Ill.; Allegheny Country Club, Edgeworth Club, Sewickley, Pa.; Duquesne Club, Keystone Athletic Club, Chicago Athletic Club, Pittsburgh Chamber of Commerce, Illinois Chapter of the Sons of the American Revolution, the Railway Men's Traffic Club, and the A.S.M.E., which he joined in 1900 as an associate. He is survived by his widow, Mary Morrison Mitchell, whom he married in 1898, and by one son, H. Morrison Mitchell.

RICHARD MOLDENKE

Dr. Richard Moldenke, one of the leading metallurgical experts of the country, died at the Muhlenberg Hospital in Plainfield, N. J., on November 17, 1930, following a major operation. He was sixty-six years old. He was born at Watertown, Wis., on November 1, 1864, the son of the Rev. Dr. Edward F. Moldenke, and Elise (Harder) Moldenke. The family moved to Plainfield in 1870, and his father was at one time pastor of St. Peter's Lutheran Church in the City of New York. He attended the Columbia Grammar School in New York and later the School of Mines of Columbia University, from which he was graduated in 1884. Two years later he returned as an instructor at Columbia and studied for his Ph.D. degree, which he received in 1887.

For a time he was employed by the United States Coast and Geodetic Survey and was identified with some of the early work in electric power development. In 1889 he organized the Mechanical and Engineering Department of the Michigan College of Mines, at Houghton, Mich. He entered the foundry industry in 1890 when he became connected with the McConway & Torley Co., of Pittsburgh, Pa. A year later he was prominent in organizing the Pennsylvania Malleable Company, at Pittsburgh, which he served as superintendent.

Dr. Moldenke became a member of the American Foundrymen's Association in 1897, when that organization was only a year old. As secretary and treasurer of the Association from 1900 to 1914, when he resigned to devote himself to his consulting practice, he built up the association from scarcely more than a trade organization to a scientific society of wide-spread influence and value. In 1925 he was awarded the Joseph S. Seaman Gold Medal of the Association in recognition of his contributions to the foundry industry. He had also been elected to honorary membership in the Association.

Through his membership in the American Society for Testing Materials, of which he was vice-president, and in the International Society for Testing Materials, Dr. Moldenke was very active in establishing specifications for foundry materials. An international standard for the comparison of cast irons was the latest work in which he played an important part.

President Roosevelt appointed him as a member of his Conservation Commission to investigate safety devices for workers in mines throughout the country. The reports which he submitted on this investigation resulted in many improvements in safety devices.

During the World War he was called upon to assist in the production of flawless castings for war materials. Among other things he specified the analysis of iron used in various castings in the Liberty motor.

Dr. Moldenke was consulting metallurgist for many companies, including the Worthington Pump & Machinery Corp., the Bethlehem Steel Company, the United States Cast Iron Pipe & Foundry Co., the American Cast Iron Pipe Company, and the Babcock & Wilcox Company.

He was a prolific writer on foundry and metallurgical subjects. Among the best known of his works are his books entitled "The Production of Malleable Castings" and "The Principles of Iron Founding."

During the latter part of his life, when not traveling in the interest of his profession, he busied himself in experimenting with metals in the small foundry in the rear of his home at Watchung near Plainfield.

Dr. Moldenke became a member of the A.S.M.E. in 1900. He also belonged to the American Electrochemical Society, the American Institute of Mining and Metallurgical Engineers, the Newark, New England, Pittsburgh, and Southern Foundrymen's Associations, the British Iron and Steel Institute, the Verein deutscher Eisen Huttenleute, and the Institute of British Foundrymen, of which he was an honorary member.

He also was active in civic and church affairs, being a member of the Kiwanis Club, the Society of Older Graduates of Columbia University, the Columbia Alumni Association, the Lutheran Society of New York, and treasurer of St. Peter's Lutheran Church, Plainfield.

His widow, Mrs. Anna (Heins) Moldenke, whom he married in 1891, two sons, Richard, Jr., and Edel Moldenke, and a daughter, Mrs. Paul Noh, survive him.

ARLINGTON G. MOLER

Arlington G. Moler, Captain, Engineers Corps, U.S.A., who served overseas during the World War and was gassed and otherwise injured, died of tuberculosis in Salt Lake City, Utah, on August 22, 1930. He was buried in the Fort Douglas cemetery with military honors.

Captain Moler was born at Brunswick, Md., on June 25, 1891. He followed his high-school education with three years at the Maryland Institute and a four-year apprenticeship with the Baltimore & Ohio R.R., in its Riverside and Mt. Clare shops. He was employed by that road during the next three years successively as gang foreman, machine-shop foreman, and general foreman, at the Mt. Clare shops.

Severing his connection with the Baltimore & Ohio, Captain Moler was for a year tool room foreman for the Eddystone Ammunition Company, Philadelphia, and subsequently assistant superintendent in charge of the manufacture of automobile wire wheels for the E. G. Budd Wheel Corp. of that city.

Since the War Captain Moler had held positions as superintendent of motive power for the Denver & Salt Lake (Moffat) Railroad, manager of the machinery department of the Salt Lake Hardware Company, and superintendent of the Williams Pipe Machine Plant at Erie, Pa.

Captain Moler became an associate member of the A.S.M.E. in 1920. He is survived by his widow.

CHARLES BREARLEY MOORE

Charles Brearley, son of Josiah and Jennie (Lindsay) Moore, was born at Macomb, Ill., on August 28, 1874. He received an M.A.

degree from Lake Forest University, Lake Forest, Ill., in 1896 and in the same year entered the contracting and building business under the name of C. B. Moore & Co., later engaging in the manufacture of heating apparatus with the Columbia Heating Company. In January, 1902, Mr. Moore joined in the organization of the American Locomotive Equipment Company, of which he was general manager until 1910. At that time he organized the American Arch Company of New York and served as vice-president until 1912, when he assisted in the organization of the Oxweld Railroad Service Company, Chicago, occupying the position of vice-president until September of that year, when he was elected chairman of the board.

From 1912 to 1917 Mr. Moore was also vice-president of the Boss Nut Company. In 1922 he organized the Ajax Hand Brake Company, of which he was president at the time of his death. In 1924 he was made vice-president of the Youngstown Steel Door Company of Cleveland, Ohio, and held that position until his death.

Mr. Moore became a member of the A.S.M.E. in 1914. He was a Presbyterian by faith, belonging to the First Presbyterian Church at Evanston, Ill., where he made his home. He held membership in the Union League Club, University Club, Collegiate Club, and Press Club of Chicago, and several country clubs. His death on November 9, 1929, was caused by heart failure. Surviving him are his widow, Fay (Harvey) Moore, whom he married in 1906, and two sons, James Herbert and Robert Brearley Moore.

ROBERT S. MOORE

Robert S. Moore, retired president of the Pacific Securities Company, San Francisco, Calif., died on February 16, 1930. Mr. Moore was born in that city on March 22, 1857, the son of Joseph and Anne Moore. After some early experience in mechanical engineering at the Reardon Iron Works, San Francisco, he entered the University of California, from which he received a B.S. degree in 1881.

Mr. Moore entered the shops of the Risdon Iron Works following his graduation, and worked up to the position of superintendent. He left that firm to found the Moore & Scott Iron Works at San Francisco. Later he founded the Moore Dry Dock Company and served as chairman of its board. This company built a large number of steamships during the World War. He also served as chairman of the board of the Paraffine Companies, Inc., San Francisco, and assistant to the president of the Moore Investment Company.

Mr. Moore became a member of the A.S.M.E. in 1892. He served as a manager of the Society in 1901–1904, and as a member of its committee on the 1915 International Engineering Congress. He also belonged to the Masonic fraternity, and a number of clubs. He married Florence Howe in 1887.

MAX PHILLIP MORRISON

Max Phillip Morrison, head of the Tramway Department of the American Steel & Wire Co., Worcester, Mass., died at Charleston, W. Va., on February 28, 1930, of heart disease. He was born in Moscow, Russia, on December 16, 1878, and came to America as a young man. He studied at Drexel Institute, Philadelphia, and was graduated from the University of Pennsylvania with the degree of B.S. in mechanical engineering in 1906. He received his M.E. degree in 1909. While working for the latter degree, Mr. Morrison was employed as plant engineer of the Chester Steel Castings Co., Chester, Pa., in 1906, and the following year by the Pennsylvania Steel Company, Steelton, Pa., as draftsman. He was evening instructor in mathematics and head of the Mechanics Department of the School of Industrial Arts, in Trenton, N. J., in 1908 and 1909 and was also employed by the Trenton Iron Company, now the American Steel & Wire Co., as a draftsman during that period.

His advancement in this company was rapid and led to his transfer to the Worcester Works as head of the Tramway Department. He designed and installed overhead tramway systems for handling materials, including many systems is mining regions.

Mr. Morrison became a member of the A.S.M.E. in 1914. He was also a member of the Worcester City Club. A daughter living in Trenton, N. J., survives him.

CHARLES LEONARD NEWCOMB

Charles Leonard Newcomb, former manager and vice-president of the A.S.M.E., consulting engineer, well known for his long connection with the Deane Steam Pump Company, of Holyoke, Mass., died on March 13, 1930, at his home in Holyoke.

Mr. Newcomb was born at West Willington, Conn., on August 7, 1854. He was the son of Charles Leonard and Martha Jane (Hudson) Newcomb. His early life was divided between working in a glass factory during the winter months and on a farm during the summer months, and he had slight opportunity for attending the district school of the locality. He was at an early age employed with the Hall Thread Company, South Willington, Conn. Later he was an apprentice in the Murless Foundry and at the Senior Machine Shop, and afterward was employed as a machinist with the Rock Manufacturing Company, Rockville, Conn., and the American Clutch Company, Middletown, Conn.

In 1874 he entered the employ of Pratt & Whitney Co., Hartford, Conn. In 1880 he was graduated from the Worcester Polytechnic Institute with the degree of M.E. He was subsequently employed as superintendent of the American Electric Lighting Company, New Britain, Conn., which afterward became the Thomson-Houston Electric Company of Lynn, Mass.

Mr. Newcomb became superintendent of the Deane Steam Pump Company in 1881. The company was acquired in 1899 by the International Steam Pump Company, and in 1914 was merged into the Worthington Pump & Machinery Corp., as the Deane Works of the corporation. Mr. Newcomb's entire connection with this plant extended over a period of 47 years, during which time he became its president and general manager, a position which he retained until he retired in 1927.

As a mechanical engineer Mr. Newcomb specialized in steam and hydraulic engineering and was a very active factor in the upbuilding of the Deane plant. During his residence in Holyoke he also acted as consulting engineer for various manufacturers of the state, and was employed as an expert in various lines of engineering work. He was associated with many valuations of plants, among which was the Holyoke Water Power Company, Gas and Electric Branch, which was taken over as a municipal plant by the city of Holyoke. He was a frequent contributor to the engineering press. In 1927 Mr. Newcomb was elected a trustee of the Worcester Polytechnic Institute.

Mr. Newcomb was instrumental in organizing the National Founders Association in 1898 and was elected its first vice-president. In 1899 he was one of those who helped to form the National Metal Trades Association, and of this organization he also became the first vice-president. In 1919 he was one of the organizers of the Engineering Society of Western Massachusetts, which he served as its first president. Through the Associated Industries of Massachusetts, which he helped to organize and which he served as a director and member of the executive committee until his death, he was active in promoting the industrial growth of New England. He became a member of the A.S.M.E. in 1883 and served as manager from 1918 to 1921, and as vice-president from 1926 to 1928. He also belonged to the Society of Naval Architects and Marine Engineers and the New England Foundrymen's Association, the Masonic fraternity, and a number of clubs.

Mr. Newcomb was specially interested in human relations in industry, and was an executive in the annual conferences of the Silver Bay Industrial Conference Board. He took an active part in the municipal affairs in the city of Holyoke, acting as councilman during the years 1886 and 1887, and as alderman in 1888. He became a member of the Fire Commission of that city and was named its chairman in 1893, serving in this capacity for 17 years. During this service he invented a widely adopted rotary deluge nozzle for fire-fighting purposes on the top of an aerial ladder. He organized the Holyoke Cooperative Bank and was its president until his death.

Surviving Mr. Newcomb are his widow, Inez L. (Kendall) Newcomb, whom he married in 1874, and six children.

HENRY C. ORD

Henry C. Ord, mechanical engineer, Tacoma, Wash., died at his home on March 7, 1930. He was born at Stockton on Tees, Durham, England, on February 20, 1867. He attended the public schools and the Toronto Art School, and served a four-year apprenticeship with the Napanee Paper Company. From 1887 to 1890 he engaged in boiler and sheet iron work with the Cleveland Shipbuilding Company and other firms. In 1890 he became draftsman for the Gobeille Pattern Company, Cleveland, Ohio, and in 1895 foreman of boiler and sheet-iron work for the McKinnon Manufacturing Company, Bay City, Mich. For several years he was draftsman and designer for the Gibbs Electric Company, Milwaukee, Wis., engineer and designer for the Vulcan Iron Works, Chicago, Ill., and engineer and designer for the Bucyrus Company, South Milwaukee, Wis. He also served as mechanical engineer and designer of engines and special machinery for the Allis-Chalmers Company, Milwaukee, Wis., the General Electric Company, Lynn, Mass., the Dominion Bridge Company, Ltd., Montreal, Canada, and the Puget Sound Iron & Steel Works, Tacoma, Wash.

He became a member of the A.S.M.E. in 1905. He was a Methodist in religion and a member of the Tacoma Revolver and Gun Club. His widow, Della (Cummings) Ord, survives him.

T. ELLIOTT PAYSON

T. Elliott Payson, engineer for special equipment with the International Motor Company, Long Island City, N. Y., died on September 14, 1930. He was born in New York, N. Y., on November 26, 1870, the son of Thomas and Lillian (Gordon) Payson.

Mr. Payson supplemented his public school education with two years at Cooper Union and private instruction. His engineering experience, beginning with the Neptune Meter Company, Long Island City, N. Y., as chief draftsman and designer, was varied. During the first fifteen years he had experience not only in drafting and designing, but also in machine shop and toolmaking. Among the companies with which he was connected during this period were the Mergenthaler Linotype Company, Brooklyn, N. Y., Randolph Clowes Company, Waterbury, Conn., Remington Typewriter Company, Ilion, N. Y., and Ideal Opening Die Company, New York, N. Y.

From 1906 to 1907 Mr. Payson was engaged in the design of machinery for the Eton-Hurlbut Paper Company, Pittsfield, Mass. He then returned to New York as assistant superintendent and production engineer for the Joseph Schneible Company. For a time in 1909 he was again located in Pittsfield, with the Alden Sampson Manufacturing Company, and during the next two years was works manager and general superintendent for The Edengraph Manufacturing Company, New York.

Mr. Payson was located in Newark and West Orange, N. J., in 1911 and 1912, part of the time at the Edison Laboratory and The Edison Storage Battery Company, in West Orange, and the remainder with the Lansden Company, Newark. He next went to Seneca Falls, N. Y., as general superintendent and mechanical engineer, engaged in the manufacture of engine lathes, machine tools, etc., for The Seneca Falls Manufacturing Company. Prior to his connection with the International Motor Company he had been located at the Presto Machine Works, in Flushing, N. Y.

Mr. Payson became an associate of the A.S.M.E. in 1906 and a full member in 1914. Surviving him are his widow, Julia (Lynn) Payson, and two daughters, Vivienne Lynn (Payson) Miller and Ruth Lynn (Payson) Stelzer.

NATHAN WAITE PERKINS

Nathan Waite Perkins, designer and consulting engineer for the National Cash Register Company, Dayton, Ohio, died on December 1, 1930, of heart disease. He is survived by his widow, Alice E. (Waite) Perkins, whom he married in 1889, and by a son, Raymond C. Perkins, and two daughters, Margaret W., and Mildred E. Perkins.

Mr. Perkins was born in St. Louis, Mo., in December, 1860. He attended Washington University in that city, from which he received the degree of M.E. in 1881. During the most of the time from then until 1906, he worked as draftsman and designer for different companies in St. Louis, among which were the American Brake Company, American Arithmometer Company, Standard Adding Machine Company, American Car Company, and Universal Adding Machine Company.

Early in 1906 Mr. Perkins left St. Louis for Newark, N. J., where he accepted a position as chief draftsman and engineer for the Ellis Adding Typewriter Company. This company was later purchased by the National Cash Register Company, by whom he was retained as designer and consulting engineer.

Mr. Perkins became a member of the A.S.M.E. in 1913. He was president of the New York Alumini of Washington University for a year, and a member of the First Unitarian Church of Orange, N. J.

ROBERT W. PETTIGREW

Robert W. Pettigrew, technical student of the Westinghouse Elec. & Mfg. Co., South Philadelphia Works, died on November 28, 1930, at Moores, Pa. He was born at Wilmore, Pa., on October 5, 1902, the son of John W. and Ada (Crum) Pettigrew. He received his high-school education at Beaverdale, Pa., and was graduated from the University of Pittsburgh, with the degree of B.S. in M.E., in 1930. He had served in the Aircraft Division of the U. S. Navy. He became a junior member of the A.S.M.E. in 1930.

ALBERT C. PICARD

Albert C. Picard, whose death on June 17, 1930, was caused by heart disease, was a native of Detroit, Mich., and had spent a large part of his life there. He was born on September 3, 1882, the son of Albert and Emily (Joliet) Picard, and after completing his studies became assistant to the secretary of the Michigan Lubricator Company. In 1910 he was made traveling sales representative of the Detroit Lubricator Company, a position which he retained for two years. Since then he had been general manager of the Lubricator Division of the McCord Radiator & Mfg. Co., of Detroit. He was in charge of design, production, and sales, and under his supervision the department became one of the most important units of the company.

Mr. Picard was always active in any development that had to do with mechanical lubrication, and contributed in no small measure to its wide use in the oil field. He designed force feed pumps, adjustable nozzles for atomizing oil, and lubricating pumps for motor vehicles.

Mr. Picard became an associate-member of the A.S.M.E. in 1929. He belonged also to the Knights of Columbus and the Detroit Golf Club, and was a Roman Catholic. His widow, Margaret F. (Foley) Picard, whom he married in 1914, survives him.

FRANCIS COLE PRATT

Francis Cole Pratt, former vice-president and chairman of the manufacturing committee of the General Electric Company, Schenectady, N. Y., died on January 26, 1930, in New York, N. Y., after an illness of six weeks.

Mr. Pratt was born in Hartford, Conn., on January 19, 1867, the son of Francis A. and Harriet Cole Pratt.

He attended the Hartford public schools and was graduated from the Sheffield Scientific School of Yale University with the degree of Ph.B. in mechanical engineering in 1888. After graduation he was associated with the Pratt and Whitney Company, Hartford, Conn., machine-tool manufacturers, of which his father was president and one of the founders, continuing with them until he became vice-president. He made several trips to Europe for the company, studying processes of treating metals, equipment of armories and factories with machinery for producing interchangeable parts, and other problems.

Mr. Pratt joined the General Electric Company in 1906 as assistant to E. W. Rice, in charge of manufacturing and engineering. He was made assistant to the president in 1913 and was elected vice-president in 1919. In this capacity he at first had charge of engineering and later of both engineering and manufacturing. He retired in 1927.

Mr. Pratt was a member of the munitions standards board of the United States council of national defense in 1917, a trustee of the Sheffield Scientific School, where he established the Francis A. Pratt scholarship fund as a memorial to his father, a trustee and former head of the Hospital Association of Schenectady, a former trustee of the Albany Medical College of Union University, and former president and member of the executive committee of the Yale Engineering Association. The honorary degree of M.A. was conferred upon him by Yale in 1925. He became a junior member of the A.S.M.E. in 1892 and was promoted to full membership in 1897. He was a chevalier of the Legion of Honor.

His widow, Mrs. Bertha De Witt Pratt, a son, Francis De Witt Pratt, and a daughter, Mrs. Charles Hooker Talcott, survive him.

AUGUSTE C. E. RATEAU

In the death of Auguste Camille Edmond Rateau, which occured in Paris on January 13, 1930, the A.S.M.E. lost one of its most eminent foreign members; one who, passing at the comparatively moderate age of 67 years, might have been expected to continue longer in its work and its activities.

Born at Royan, in the Department of Charente-Inférieure, on October 13, 1863, Auguste Rateau received his technical education in the famous École Polytechnique in Paris, being graduated at the head of his class (1881–1883), after which he passed three years at the École Supérieure des Mines, followed by a year of active service in the Government Mining Engineering Corps at Rodez. For the ten years between 1888 and 1898 he served as professor in the School of Mines at Saint Étienne, and during the years from 1902 to 1910 as lecturer upon industrial electricity in the High School of Mining Engineering at Paris.

It was during these latter years that Rateau began to devote his energies to his special inventions, and to their industrial and commercial development in France and elsewhere in Europe. The result of this work was the inception, with only five associates, in 1903 of the great Société Rateau, which, at the time of his death, engaged more than 4000 employees, with branches in most of the industrial centers of Europe. Of this great corporation he was the Chairman of the Board, and was also actively and officially connected with other industrial organizations.

As a professor he always exercised a most stimulating influence upon the students under his charge, while at the same time employ-

ing his original genius upon the subject of the mechanics of fluids and its application to steam turbines, to centrifugal compressors, and to centrifugal pumps. Centrifugal compressors of the Rateau type have come into general use in France and elsewhere for blast furnaces and steel converters; while his device of the steam accumulator has enabled the exhaust steam of reciprocating engines to be successfully utilized in low-pressure steam turbines.

In 1900 he published his treatise on turbo machines, a work which still retains its value for engineers in this department of practice.

During all the period in which Rateau was occupied with the development of the great industrial organization of which he was the head, he found time to conduct technical researches of fundamental value in the department of engineering to which he was devoted. The pages of the leading engineering publications of France are filled with communications of the highest scientific character from his fertile brain, and deal with turbo machines, pressure blowers, air screws, flow of gases through nozzles, ejector condensers, etc.,

More recently he gave much attention to the mechanics of aviation and the reactions of air resistance to the wings of airplanes.

Twice he was laureate of the Academy of Sciences, receiving the Fourneyron Prize in 1899, and the Poncelet Prize in 1911; at which time he was chosen a Member of the Insitute of France, one of the highest honors to which a citizen of France may aspire; and to this was added that of Commander of the Legion of Honor.

When the Great War burst upon France, Rateau, although beyond the call for active military service, at once offered himself to the National Defense, and in connection with the Manufacture d'Armes at St. Étienne, he organized a model workshop, which under his able personal administration, produced more than four million shells. At the same time he developed his remarkable invention of the automatic supercharger for the motors of airplanes, enabling higher altitudes to be attained than had hitherto been possible, and thus giving French military airplanes a distinct advantage.

In connection with the ordnance department of the French army, Rateau developed improvements in the control of pneumatic recoil mechanism in artillery, of such importance that these devices have been kept secret by the government as valuable contributions to the national defense.

As an indication that his activities were unimpeded to the last, his latter days were devoted to the development of a most effective system of supercharging for the Diesel motor—researches of which the effects are yet to be made public.

Space will not permit an enumeration of the many contributions to engineering knowledge which have emanated from the fertile brain of Auguste Rateau—they fill a considerable volume, separately published, and sought and appreciated by the members of the profession; many of them are highly technical and analytical, showing an intimate knowledge of mathematical theory combined with practical application.

Many honors were conferred upon Auguste Rateau; it is necessary here to mention only that he received the doctorate from four institutions in as many countries: from America (University of Wisconsin), from England (University of Birmingham), from Belgium (University of Louvain), and from Germany (Technische Hochschule, Charlottenburg).

In all his active career, Rateau was always genial, courteous, and accessible, even to the least important members of his organization; never egotistical or dogmatic, always friendly and affectionate.

Often he repeated his controlling thought:

"Happy is he who succeeds in delivering his message!"

Auguste Rateau was elected Honorary Member of the A.S.M.E. in 1919, and always manifested a great interest in its work and its members.

HENRY HARRISON SUPLEE.[1]

OLIVER PERRY REESE

Oliver Perry Reese, general superintendent of the southwestern division of the Pennsylvania Railroad since June, 1929, died at his home in Indianapolis, Ind., on November 14, 1930, as the result of heart disease.

He was born in Louisville, Ky., on May 29, 1876, and was graduated from Purdue University in 1898, with a B.S. degree in mechanical engineering. He served an apprenticeship with the Louisville and Nashville Railroad at Louisville during the next two years and entered the service of the Pennsylvania Railroad as a draftsman at the Allegheny shops in 1900. During the next fifteen years he served the company in special work at Fort Wayne, Ind., as gang foreman of the machine shop at Allegheny, Pa., general foreman and master mechanic of the E. and A. Division and at the Ally Shops, and assistant engineer of motive power of the northwestern system.

In 1917 he became superintendent of motive power at Toledo, and in 1921 was transferred in the same capacity to Chicago. In 1927 he was made general superintendent of motive power at Pittsburgh.

Mr. Reese was a member of the Masonic fraternity, Columbia Club, Indianapolis Athletic Club, and Highland Golf and Country Club. He had been a member of the A.S.M.E. since 1916.

KNIGHT CHENEY RICHMOND

Knight Cheney Richmond, consulting engineer and architect, Providence, R. I., died on December 22, 1930, of heart disease.

Mr. Richmond was born in Brooklyn, N. Y., on April 18, 1864. He received a B.P. degree from Brown University in 1885 and five years later a B.S. from the Massachusetts Institute of Technology. He had also served an apprenticeship with the Providence Steam Engine Works.

Following graduation, Mr. Richmond entered the office of Nier, Hartford and Mitchell, at Chattanooga, Tenn., as a draftsman. The following year he became treasurer of the P. A. Demens Woodworking Co., at Asheville, N. C., where he remained for two years. He then was appointed resident engineer for the Crompton Company, textile manufacturers, at Crompton, R. I. He resigned this position in 1899 to become associated with F. P. Sheldon, mill engineer of Providence, as draftsman and engineer, and retained that position until he opened his own office in 1903.

Mr. Richmond's consulting work included steel and reinforced concrete construction, power equipment, reports and estimates, and textile mills and factories. A paper by him on Saw-Tooth Roofs for Factories, presented at the 1906 Annual Meeting of the A.S.M.E., was published in the Transactions for 1907. He became a junior member of the Society in 1891, and a member in 1908. He also belonged to the American Concrete Institute.

ANDREW LAWRENCE RIKER

Andrew Lawrence Riker, engineer and inventor, and a pioneer in the development of the automobile in this country, died suddenly of heart disease on June 1, 1930, at his home in Fairfield, Conn. Mr. Riker was a native New Yorker, and was born on October 22, 1868, the son of William J. and Charlotte L. R. (Stryker) Riker. He received his education at Columbia University.

From youth Mr. Riker showed his inventive ability, having designed and built a tricycle propelled by electricity when only 16 years old. In 1895 he produced a four-wheeled electric motor car and in 1902 a car using gasoline for fuel. In 1908 the Vanderbilt Cup race was won by a car of his design, driven at a speed of 64.5 miles per hour.

At the age of 20, Mr. Riker was president of the Riker Electric Motor Company, which introduced commercially the first toothed electric armature. Among the first electric automobiles and trucks used in New York were those of the Riker design.

In 1902 Mr. Riker joined the Locomobile Company of America and became its vice-president and chief engineer. The company abandoned its popular-priced steam cars for the gasoline-fueled type of vehicle, the first of which was designed by Mr. Riker. It had many engineering features, new at that time, including sliding gear transmission, steel frames, and high-tension ignition.

In 1900 the French government awarded Mr. Riker a medal for his part in the growth of motor-car science. He was appointed a member of the Naval Consulting Board in 1915 and became chairman of its committee on internal combustion motors.

Mr. Riker became an associate member of the A.S.M.E. in 1897 and a member in 1899. He served as manager from 1906 to 1909. He was the first president of the Society of Automobile Engineers and held that office for three terms. He also belonged to the American Institute of Electrical Engineers, the Automobile Club of America, the British Institute of Automobile Engineers, the New York Electrical Society, and the Society of Mayflower Descendants. His club memberships included the Engineers, University, Transportation, Fairfield Country, Pequot Yacht, and the Pootatuck Yacht Club.

He is survived by his widow, Edith (Whiting) Riker, whom he married in 1890, and by three children, Edith Whiting, Charlotte Lawrence, and Andrew Lawrence, Jr.

EDWARD AUSTIN RIX

Edward Austin Rix, whose death following a stroke occurred on January 8, 1930, at Oakland, Calif., was born at San Francisco, Calif., on January 29, 1855. He was graduated from the University of

[1] Paris, France.

California with the degree of Ph.B. in 1877, and spent the following six months as an apprentice at the Phoenix Iron Works, San Francisco. After being employed there as foreman for a little more than a year, Mr. Rix started a small shop of his own in May, 1879. About 1881, he assisted in the conversion of the Idaho plant at Grass Valley, Calif., from steam to water power. It was at this plant that the first tests of the Pelton wheel were made.

In 1883 Mr. Rix became the proprietor of the Phoenix Iron Work and in conjunction with J. K. Firth, designed, built, and operated pneumatic machinery. In 1888 they undertook also the building of locomotives and refrigerating points on the Linde system. The company furnished and erected structural steel work for many of the principal city buildings, designed and erected hoisting works, pumping plants, and pneumatic plants for mines, designed and successfully operated the first pneumatic locomotive ever operated on the Pacific Coast, built stamp mills and power tramways, and built Corliss engines and many slide valve engines of its own design.

Mr. Rix sold out his share in the business to Mr. Firth in 1890 and founded the Rix Compressed Air Machinery Company, of San Francisco, subsequently known as the Rix Company, Inc. The Company had its own shop for light construction work, and heavier work was done by the Fulton Engineering and Shipbuilding Works under his supervision.

Mr. Rix introduced the system of economy guarantees for steam plants; designed and erected near Lima, Peru, extensive works for manufacturing lard and curing meats; designed and superintended the construction and testing of the pneumatic plant at the North Star Mine, Grass Valley, Calif.; designed and furnished the power plant for the Alaska Treadwell Mill, Alaska; designed and superintended the erection of the pneumatic plant for the U. S. Government at Presidio, Calif.; and installed a steam and condensing plant and the first motion Corliss hoisting works for the S. F. and S. J. Coal Co., at Livermore, Calif.

Mr. Rix was known throughout the world as one of the outstanding authorities on the uses and development of compressed air as a unit of power. He held 35 patents on his inventions. Among these are included the compressed air automatic hammer; the first directly connected tangential water wheel on an air compressor, 1880; the air compressors for the dynamite gun plant at Ft. Riley, 1896; the first liquid air on the Pacific coast; the first air lift test plant used by Dr. Poehl, the inventor; the first variable volume air compressor, 1899; and the first supercharger air compressor.

He was awarded the gold medal of the Pacific Gas Association for his treatises on gas transmission and compression; was the reader of the first paper in California on liquid air at Stanford University in 1895; and published the first handbooks on compressed air engineering and the use of hammer drills in mining.

Mr. Rix was one of the founders of the famous Olympic Club of San Francisco and belonged to the Athens Club and the Claremont Country Club. He also was a member of the American Society of Civil Engineers, The American Society of Mechanical Engineers, which he joined in 1896, the Durant Rhetorical Society, and other scientific organizations.

Surviving Mr. Rix are his widow, Gail Wheeler (Shipman) Rix, of Emerson, Iowa, whom he married in 1913, and one daughter, Elizabeth.

EDWARD PARKINSON ROBERTS

Edward Parkinson Roberts, consulting engineer and statistician, member of the firm of Roberts & Abbott, Cleveland, Ohio, died on October 20, 1930. He was the city's first smoke commissioner (1912–1914) and was president of the Cleveland Engineering Society from 1911 to 1913.

Mr. Roberts was born in New York, N. Y., on August 29, 1857, and was graduated from the Stevens Institute of Technology with the class of 1877. For the next two years he was employed successively as lathe hand by the Singer Sewing Machine Company; draftsman by T. S. Crane, patent agent, Newark, N. J.; and machinist and superintendent by George Yale, Newark. During the winter of 1878-1879 he also taught evening classes in mechanical drawing. In the Fall of 1879 he secured employment as draftsman for Hewes and Philips, Newark, but left there not long afterward to learn the business of incandescent lamp manufacturing at the U. S. Electric Light Company, New York. After some training there and with Edward Weston in his laboratory at Newark, he became superintendent and electrician of the incandescent department of the American Electric Light Company, New York. Early in 1883 he was sent to California by a syndicate of this company. His next connection was with the Swan Lamp Company, Boston, which lead to his engagement by the Rocky Mountain Brush Company to erect and start in operation electric light plants of the Brush-Swan system throughout their territory. Among others he installed the incandescent system for the Cheyenne Elec. Light & Gas Co., and was engaged by them as general manager and electrical engineer. He also was vice-president of the Fort Collins, Colo., Elec. Light Co.

In 1888-1889 Mr. Roberts was an associate professor of electrical engineering at Cornell University and for the next four years was manager of the Swan Lamp Manufacturing Company of Cleveland. He had been engaged in consulting practice since that time.

Mr. Roberts was a member of the electrical jury which passed on displays for the St. Louis World's Fair in 1904, and was secretary of the Section on Practice of the International Electrical Congress held at the Chicago World's Fair. He had contributed many articles on smoke abatement, economic operation of electric light plants, and electric railways to the technical press and to meetings of technical societies.

Mr. Roberts became a member of the A.S.M.E. in 1889 and served on special committees for the Cleveland meeting in 1912. He is survived by his widow and two children.

WILLIAM S. ROUX

William S. Roux, designer for the National Cash Register Company, Dayton, Ohio, died in that city on April 13, 1929. He was born at Chillicothe, Ohio, on July 2, 1879, and received his education in the high school and at the Ohio Mechanics Institute.

His professional experience began as designer of electric motors and dynamos for the Barriet Electric Company (now B. A. Wesche Elec. Co.), Cincinnati, Ohio, in 1899, and in 1903 he became machine-shop foreman for that company. For two years he was draftsman for the Bullock Electric Company, Cincinnati, Ohio. He joined the National Cash Register Company in 1906. His work consisted of making layouts of mechanism and supervising the detail and assembly drawings for making model parts and assembling model machines.

Mr. Roux became a member of the A.S.M.E. in 1927. He also belonged to the Masonic fraternity. He was unmarried.

WILLIAM NEWTON RYERSON

William Newton Ryerson, president of the Trojan Engineering Corporation, and a director of the Peoples Light and Power Corporation, New York, N. Y., died at his residence in the Hotel Shelton, on the morning of July 7, 1930, after an illness of several months.

He was born in New York on December 7, 1874, the son of William Tunis Ryerson and Julia Hart (Newton) Ryerson. He attended the New York public schools, Columbia Grammar School, and the School of Mines of Columbia University, from which he was graduated in 1896 with the degree of Electrical Engineer.

Following his graduation, Mr. Ryerson was employed by the Sprague Electric Elevator Company, Bloomfield, N. J., on electrical testing and drafting, from November, 1896, to January, 1898. In the same year, 1898, he worked as draftsman for the Western Electric Company, New York, and as assistant to the chief engineer of the Waldorf Astoria Hotel.

In October, 1898, Mr. Ryerson became associated with the Metropolitan Street Railway Company of New York on construction and power work and substation operation, remaining with them until June, 1901, when he left to form a connection with the Manhattan Railway Company as chief operator of their steam electric generating station.

His chief interest at that time seemed to be in electric railways and subways and in October, 1901, he became superintendent of the substations for the Interborough Rapid Transit, with which concern he remained until April, 1905.

About that time, some of the big hydro developments on the Canadian side of Niagara Falls were started, and Mr. Ryerson became assistant superintendent of construction for the Niagara Construction Company, and later in the same year, superintendent of construction for the Ontario Power Company, Niagara Falls, Ontario, which position he held until January, 1909.

He then left the East to become general manager and chief engineer, and also a director, of the Great Northern Power Company, at Duluth, Minn. He was in this position for more than thirteen years, and it was here that he became well known among the light and power companies of the country, serving on several committees of the National Electric Light Association. About the time the Duluth properties were acquired by the Electric Bond & Share Company, Mr. Ryerson left to form a connection with Day & Zimmermann of Philadelphia, as assistant manager of the Public Utility Management Department, where he supervised the details of operation of all the utility properties, budgets, new business, rates, public relations, accounting, and major construction progress.

In January, 1925, the United Gas Improvement Company of

Philadelphia made him assistant to the vice-president, in charge of operations and engineering. His duties involved supervision of operations of gas and electric properties, budgets, rates, and engineering projects. One of his principal undertakings while there was an investigation and preparation of a report on a superpower scheme, involving the pooling of resources of several electric utilities in New York, New Jersey, and Eastern Pennsylvania.

When the Trojan Engineering Corporation was organized in September, 1928, Mr. Ryerson became its president, which position he held at the time of his death. He also served for a brief period as vice-president and general manager of the Green Mountain Power Corporation of Vermont, a subsidiary of the Peoples Light and Power Corporation, of which he was a director.

Mr. Ryerson was a fellow of the American Institute of Electrical Engineers and a member of The American Society of Mechanical Engineers, which he joined in 1906, the National Electric Light Association, the International World Power Conference, the American Gas Association, and The Engineering Institute of Canada.

He married Miss Martha Taft, of Brooklyn, in 1900. His widow, two sons, William Newton Ryerson, Jr., and Philip Ryerson, and a daughter, Mrs. Charles W. Newkirk, of Philadelphia, survive him.

GEORGE DE GROAT RYTHER

George De Groat Ryther, president of Ryther & Pringle Company, Carthage, N. Y., died at his home on April 20, 1930. He was born at Theresa, N. Y., on June 27, 1864, the son of Charles Peter and Mary (De Groat) Ryther. He received his education in the Carthage High School and at Cornell University, where he was graduated in 1887.

Following graduation he became draftsman for the Rome, Watertown and Ogdensburg Railroad, at its shops in Oswego, N. Y. Since 1892 he had been identified with the Ryther & Pringle Company, serving successively as machinist, draftsman, foreman, superintendent, and president. He was the inventor of a sectional cable conveyor, a material shredding machine, and a paper stock refiner.

Mr. Ryther became a member of the A.S.M.E. in 1918, and also belonged to the Masonic fraternity and several clubs. He was an Episcopalian in religion. In 1892 he married Jennie Isabel Cutler, who survives him.

JAMES EDWARD SAGUE

James Edward Sague, for many years connected with the Worthington Pump & Machinery Corporation, died at Cliffdale, his Poughkeepsie, N. Y., home, on May 9, 1930.

Mr. Sague was born at Poughkeepsie on July 20, 1862, the son of Horace and Harriet Jane (Kelsey) Sague. He was graduated from the Stevens Institute of Technology at Hoboken, N. J., in the class of 1883, receiving the degree of M.E. His graduation thesis covered "A Report on the Trial of the Steamer *City of Fall River*," and was published in the *American Engineer* and the *Journal of the Franklin Institute*.

From 1883 to 1892 he was engaged in railroad work. During this time he spent two years as mechanical engineer for the West India Improvement Company and master mechanic of the Jamaica Railroad, Jamaica, W. I., following which he was engaged with the Schenectady Locomotive Works from 1892 to 1901.

From 1901 to 1907 he was chief mechanical engineer and later was vice-president of the American Locomotive Company.

During the first administration of Governor Hughes in 1907, Mr. Sague was appointed a member of the Public Service Commission for the Second District, controlling all public utilities in New York State outside of New York City. He held this office for seven years with great credit to the Commission and himself. While with the Public Service Commission, he was chosen chairman of the Committee on Rails and Equipment of the National Association of Railroad Commissioners.

In 1916 the American Manufacturers Export Association organized the American Industrial Commission. This commission visited France to ascertain how American resources might best be made available for the reconstruction of the devastated regions and with the hope of furthering Franco-American trade relations. Mr. Sague was a member of this commission.

In June, 1916, he was chosen chief consulting engineer of the Worthington Pump and Machinery Corporation. In March, 1918, he was elected a member of the board of directors and vice-president in charge of engineering and manufacturing, and as such directed Worthington's large production of war material.

Mr. Sague resigned as vice-president of Worthington in 1926, but remained a director of the company until his death.

For several years prior to his death he was chairman of the Reorganization Committee of the Middle States Oil Company, and upon its rehabilitation in 1930 as the Middle States Petroleum Company he became a member of the board of directors and a voting trustee. He was at the same time president of the Sague Realty Company of Poughkeepsie.

Mr. Sague was married in 1890 to Miss Jeanette Kenyon of Brooklyn, N. Y.; and after her death to Miss Mary Landon, a professor at Vassar College, who, together with his daughter, Mrs. Sterling Carter, of Poughkeepsie, survive him.

Mr. Sague joined the A.S.M.E. in 1887, and was vice-president of the Society in 1914–1916.

JOHN JOSEPH SCOLLAN

John Joseph Scollan, whose death occured on January 5, 1930, was a native of Elizabeth, N. J., where he was born on September 24, 1870. He attended St. Henry's School in that city and then served an apprenticeship in the shops of the Central Railroad of New Jersey.

From 1896 to 1903 Mr. Scollan was employed by the Crescent Shipyard Company at Elizabeth, a year each as machinist and foreman machinist, and five years as chief engineer. He spent seven years at sea, first as junior and subsequently as chief engineer, and for a year and a half was in the employ of the Japanese government in charge of the design, installation, and trials of war vessels.

Mr. Scollan was first located in Canada as superintendent of mechanical erection for the Canada Foundry Company, Ltd., at Toronto. He was advanced to the position of mechanical engineer in this company, and had charge of the manufacture of boilers and general machinery.

After leaving the employ of the Canada Foundry Company, Mr. Scollan became general superintendent for the Canadian Allis-Chalmers Company at the Niagara Shipyards, at Bridgeburg, Ontario.

He returned to the United States about 1919 to accept a position with the Submarine Boat Corporation, Newark, N. J.

Mr. Scollan became a member of the A.S.M.E. in 1910. He was also an Elk.

MICHAEL JACOB SHAMRAY

Michael Jacob Shamray, son of Jacob and Anna (Shulova) Shamray, was born at Kremenchug, Russia, on July 23, 1862. He attended the classical gymnasium at Kherson, Russia, receiving the degree of Academic Maturity in 1880. He also studied at the Petrograd Technological Institute, and received an M.E. degree from the Royal Saxon Polytechnikum, Dresden, Germany, in 1886.

During the next few years Mr. Shamray worked on the design of special machinery for paper mills, water turbines, and steam engines in Dresden, and design and construction of railway shops for the Libau-Romen Railroad, Russia. In 1889 he accepted a position as superintendent of car repair shops for the Bulgarian State Railway, Sofia, and he was engaged in municipal work in Bulgaria from then until 1902. He was classed by the Ministry of Public Works as first grade mechanical engineer and was in responsible charge of the following works: city survey and planning, including water supply, public buildings, reconstruction of dams, and power development, City of Stanimaka; revising and checking of city plan and construction of public buildings, City of Kustendil; correction and flood regulation of Maritsa River, water supply, and city survey, City of Philippople; and general municipal work in the Province of Tatar-Bazardjik. A number of inventions by him during these years were patented in Germany and Bulgaria.

Mr. Shamray came to the United States in 1902 and spent the first year in standardizing parts of special machinery for the International Postal Supply Company, New York. For the next three years he was engaged in the design of railroad cars for the Goodwin Car Company, New York. Since 1906 he has been associated with George F. Hardy, of New York, in consulting engineering practice. His work dealt particularly with reinforced concrete and hydraulic engineering in connection with the design of more than fifty paper mills and water-power developments in the United States and Canada. He had contributed a number of articles to the technical press.

Mr. Shamray became a member of the A.S.M.E. in 1923. He also belonged to the Russian Engineering Association in the United States and the American Society of Civil Engineers. He was active in charitable work, being a member of the Jewish Federation of Charities, Jewish Consumptive Relief Society, Welfare League Association, National Home for Jewish Children at Denver, New York Association for the Blind, Inc., National Society for the Prevention of Blindness, and New York Guild for the Jewish Blind. He was also a member of the Boy Scouts Foundation of Greater New York. He was interested in astronomy and mathematics and belonged

to the Amateur Astronomers of the American Museum of Natural History.

Surviving Mr. Shamray are his widow, Pauline Ortman Shamray, whom he married in 1906, and one son, Peter Leo Shamray. Mr. Shamray was killed by an automobile in New York on December 23, 1930.

WILLIAM MILLER SHAW

William Miller Shaw, president of the Benj. F. Shaw Co., Wilmington, Del., died suddenly of heart trouble at his home there on September 3, 1930.

Mr. Shaw was a native of Wilmington, having been born there on October 8, 1882, the son of Benjamin F. and Helen Shaw. He was educated in the Wilmington public and high schools and attended the Wilmington Military Academy. He entered the shops of the Benjamin F. Shaw Company, of which his father was president, and was soon promoted to office work, and then to the mechanical office, and in 1908 was elected first vice-president and general manager of the company. In 1927, upon the death of his father, he succeeded to the presidency of the company, which position he retained until his death. He was also well known in Atlantic City, where he had a home.

Mr. Shaw became a member of the A.S.M.E. in 1915. He also belonged to the Masonic fraternity.

He is survived by his widow, Clara E. Rotthouse Shaw, and four children, Benjamin F. Shaw, 2nd, Miss Elizabeth Shaw, W. Miller Shaw, Jr., and Robert Frederick Shaw.

THOMAS SHIPLEY

Thomas Shipley, president of the York Ice Machinery Corporation, York, Pa., died on January 22, 1930. Mr. Shipley had been a member of the A.S.M.E. since 1891, was a charter member and president in 1912 of the American Society of Refrigerating Engineers, and also belonged to the National Association of Practical Refrigerating Engineers and the American Association of Ice and Refrigeration. He had presented papers on refrigeration at meetings of these and other societies and through both his society and business affiliations was very well known in the refrigeration industry.

Mr. Shipley was born at Jersey City, N. J., on June 30, 1861. He attended Cooper Institute, from which he was graduated as a mechanical engineer in 1882. During his years at Cooper Institute and for several years thereafter he was employed as a draftsman by the Morris & Cummings Dredging Co. of Jersey City, and the Babcock & Wilcox Boiler Co. and the firm of Wood and Richmond in New York, N. Y. In 1885 and 1886 he was associated with Wm. H. Wood in the firm of Wood & Shipley, designing and building ice machinery. Mr. Wood, likewise a prominent figure in refrigeration and a member of the A.S.M.E., died in July, 1930.

From 1887 to 1893 and again from 1895 to 1897 Mr. Shipley was identified with the Frick Company of Waynesboro, during the latter period as manager of the ice and refrigerating machinery department. During the intervening period he was president and general manager for a year of the Steubenville Ice Manufacturing Company, at Steubenville, Ohio, and operating engineer for two years of the Chautauqua Lake Ice Company at Pittsburgh, Pa.

Mr. Shipley became vice-president and general manager of the York Manufacturing Company in 1897. Other firms which he had served either as president or treasurer included the York Milk Machinery Company and York Oil & Chemical Co., York, Pa.; Bay State Construction & Supply Co., Boston, Mass.; Shipley Construction & Supply Co., Brooklyn, N. Y.; Central Construction & Supply Co., Philadelphia, Pa.; Southern Construction & Supply Co., Atlanta, Ga.; Greenwood Construction & Supply Co., Pittsburgh, Pa.; and York-Ohio Ice Machine Company, Cleveland, Ohio.

GEORGE MARSHALL SINCLAIR

George Marshall Sinclair, whose death occurred on August 21, 1930, was born at Milwaukee, Wis., on June 10, 1861. He secured the degrees of A.B. in 1881 and A.M. in 1884 from Princeton University, and an M.E. degree from Stevens Institute of Technology in 1884.

Following the completion of his college work Mr. Sinclair became assistant to the chief engineer of the Midvale Steel Works, Philadelphia, Pa., where he remained for three years. After spending some time in Germany and England, visiting iron and steel works, and working for two years in the ordnance and marine forging department of the Bethlehem Steel Company, he returned to the Midvale Steel Works in 1890 to work on design.

In 1893 Mr. Sinclair opened an office as consulting engineer. From 1895 to 1905 he served as secretary and treasurer of the Philadelphia Machine Tool Company and its successor, the Falkenau-Sinclair Machine Company. Since that time he had maintained an office as consulting engineer in Philadelphia, served as director in a few small manufacturing companies, and given a large portion of his time to selling engineering equipment.

Mr. Sinclair became a junior member of the A.S.M.E. in 1887 and a full member in 1890.

BRONSON HASBROUCK SMITH

Bronson Hasbrouck Smith died in Los Angeles, Calif., on June 6, 1930, after a long illness. He is survived by his widow, Florence Merwin Smith.

Mr. Smith was born in Brooklyn, N. Y., on May 9, 1880. After studying mechanical engineering for two years at Cornell University he became assistant to the general manager of the Perth Amboy Shipbuilding Company, Perth Amboy, N. J. From this company he went in 1902 to the employ of the Holland Submarine Torpedo Boat Company as machinist and in 1903 and 1904 was designer and assistant to the superintendent of the F. H. Lovell Mfg. Co.

For about ten years Mr. Smith was identified with Westinghouse, Church Kerr & Co., as draftsman and designing engineer. He had charge of the construction of railway stations in New York, Toronto, and Chicago, power plants in Worcester and Meriden; railway shops for the Canadian Pacific Railway and the Central Railroad of New Jersey; and power houses for several other railways and companies. He also made appraisals on several hydroelectric plants.

Mr. Smith left the Westinghouse company in 1913 to become general superintendent in charge of maintenance and operation of railroad and steamboat lines for the Jamestown, Chautauqua & Lake Erie R. R. After two years with that road he accepted a position with the United Gas & Elec. Corp., part of his work being the design and construction of steel motor cars for railways. As engineer for Henry E. Kent & Co. from 1915 to 1920 he designed and supervised the construction of power plants and factory buildings for a large number of companies including the Spicer Manufacturing Corporation, American Brass Company, and National Analine & Chemical Co. Following a period as chief mechanical engineer for the American Cotton Oil Company, New York, N. Y., Mr. Smith went to Los Angeles, where he was managing engineer for Meyer & Holler, Inc., for some years. He had charge of the construction of the Petroleum Securities Building, the Chinese Theater in Hollywood, and many other large buildings.

Mr. Smith had been a member of the A.S.M.E. since 1921.

PETER E. SMITH

Peter E. Smith, designing engineer for Louis T. Klauder, of Philadelphia, Pa., at the time of his death on January 28, 1930, was born in Washington, D C., on July 31, 1888. Following his high school work he entered Drexel Institute, from which he was graduated in 1908. All of his business connections were with Philadelphia companies. During the four years following graduation he was employed by the American Heating & Ventilating Co., the latter part of the time being spent in laying out installations for public buildings. He next spent a year each with the Philadelphia Electric Company, working on piping layout for one of its stations, and with the American Engineering Company, making setting drawings for stoker installations.

In 1914 Mr. Smith took a position as designing draftsman with the Pennsylvania Flexible Metallic Tubing Company; his work included the supervision of foundry and machine shop and the erection of machinery and new buildings. Three years later he became design engineer for the Roach Stoker Company, in complete charge of design and drawing room, and also new equipment for the plant. Prior to his association with Mr. Klauder he was field engineer for a time for the United Gas Improvement Contracting Company.

Mr. Smith became an associate-member of the A.S.M.E. in 1922.

STEPHEN RAYMOND SMITH

Stephen Raymond Smith, tool designer for the Victor Talking Machine Company, Camden, N. J., died suddenly on June 10, 1930.

Mr. Smith was born at Windber, Pa., on August 19, 1898. Prior to the World War he worked in the machine shop and foundry of the Marion Steam Shovel Company, Marion, Ohio. He enlisted in the U. S. Army in 1916 and saw overseas service. Following the War he worked for two years as detail draftsman in the maintenance department of the Baldwin Locomotive Works at Philadelphia.

From 1920 to 1922 Mr. Smith attended the Brown College Preparatory School at Philadelphia, and after a summer school course in mathematics at the University of Pennsylvania, entered Rens-

selaer Polytechnic Institute, where he took three years' work in mechanical engineering.

Mr. Smith returned to the employ of the Baldwin Locomotive Works in 1925 and remained there for two years, engaged in design work. In 1927 and 1928 he was connected with the Edw. G. Budd Mfg. Co., on the design of dies, etc., for steel automobile bodies, and the John Warren Watson Company, manufacturers of the Watson stabilators, on tool and machine design. He had been with the Victor Talking Machine Company since 1928.

Mr. Smith was a new member of the Society, having joined as a junior member only about six months before his death. He is survived by his widow, Dorothea C. Smith.

WILLIAM GAGE SNOW

William Gage Snow, manager of the Middlesex Products Company, Boston, Mass., died on February 14, 1930. He had been a member of the A.S.M.E. since 1905.

Mr. Snow was born at Watertown, Mass., on Feburary 16, 1866. Following his receipt of an S.B. degree from the Massachusetts Institute of Technology in 1889 he spent two years in the drawing room of the B.F. Sturtevant Co., at Jamaica Plain, Mass., and then for two more years was in charge of installation work throughout New England for the Company.

For five years beginning in 1894 Mr. Snow was employed by the Walker & Pratt Mfg. Co., Boston. He designed heating and ventilating systems for schools and other public buildings and laid out the steam power plant and blower system for a new plant for the company. A treatise on Furnace Heating written by him during these years was published by the David Williams Company.

After leaving the Walker & Pratt Co., Mr. Snow engaged in heating and ventilating work, particularly in investigations and reports, for the S. Homer Woodbridge Co., Boston. In 1901 he went to Philadelphia as chief heating and ventilating engineer for Francis Bros. & Jellett, Inc. Among the heating, ventilating, and mechanical plants for which he made plans and specifications were those at the Bellevue-Stratford Hotel in Philadelphia, the U. S. Court House and Post Office at Indianapolis, and the Camden County Court House.

Mr. Snow prepared heating and ventilation courses for two correspondence schools and while in Philadelphia lectured on this subject at the University of Pennsylvania.

Mr. Snow returned to Boston as New England manager of Warren Webster & Co., of Camden, N. J. Prior to his connection with the Middlesex Company he was for about six years treasurer of the Reversible Collar Company in Boston.

ELMER AMBROSE SPERRY

Elmer Ambrose Sperry, past-president of the A.S.M.E., engineer and inventor, whose name will always be associated with the development of devices involving the gyroscope, died at St. Johns Hospital, Brooklyn, N. Y., on June 16, 1930, as a result of complications which set in after he had practically recovered from an operation.

Mr. Sperry was born at Cortland N. Y., on October 12, 1860. He was the son of Stephen Decatur and Mary Burst Sperry, and a descendant of Richard Sperry, who emigrated from England in 1634 and who, in 1666, at New Haven Colony in Connecticut, secreted on his farm in what is now known as Judges Cave, Whalley, Goffe, and Dixwell, three of the regicide judges who had condemned King Charles I to death.

Mr. Sperry attended the State Normal School at Cortland, and spent the college year of 1879-1880 at Cornell University. In 1876, through arrangements made possible by the Y.M.C.A. of Cortland, N. Y., he visited the Centennial Exposition in Philadelphia, and here received an imperishable inspiration for a career of invention. To this experience, which introduced him to engineering and determined his life's work, he paid magnificent tribute by leaving in his will the sum of $1,000,000 to the Y.M.C.A.

One of Mr. Sperry's early contributions to the electrical industry was an improved form of Gramme dynamo for arc lighting and an arc lamp for use with the machine. He secured the adoption of lamp and dynamo, and in 1880 founded the Sperry Electric Company of Chicago in order to manufacture these and other electrical appliances.

In 1883 he erected on Lake Michigan an electric beacon 350 ft. high, the highest in the world, and equipped it with 40,000 candlepower of arc lights.

In 1888 he was the first to build electrical mining machinery. His machines have been widely used, and started a distinct advance in mining.

About 1890, he became a designer of electric street-railway cars and soon founded the Sperry Electric Railway Company of Cleveland, Ohio, to build them. In 1894 the patents were purchased by the General Electric Company. He then designed electric carriages and manufactured them for several years. With a storage battery invented by him he was able to drive an electric carriage the remarkable distance of 100 miles. In 1896 he drove the first American-built automobile in Paris. A number of his electric carriages were sold there.

Electrochemistry also interested Mr. Sperry. He originated a process for caustic soda and bleach which still continues to be used extensively because a second large plant has recently been put into operation. Under other Sperry patents the National Battery Company was organized. He invented a detinning process for recovering tin from old cans and scrap, and an electrolytic process for producing white lead from wastes of copper mines. He invented machinery for producing fuse wires. On this invention the Chicago Fuse Wire Company was established.

In 1918 Mr. Sperry announced his high-intensity arc searchlight, having a brightness 500 per cent greater than that of any light previously made. It has high actinic value and has made possible indoor photographing of motion pictures without the sun. It is a great aid in the navigation of air and water, and is the standard searchlight for the principal armies and navies of the world.

Mr. Sperry devoted much thought, energy, and money to the development of compound internal-combustion engines using low-grade fuel oil. His compound Diesel engine, for a given horsepower, has about one-fifth the size and weight of the ordinary types.

About 1896, Mr. Sperry turned his attention to making practical use of the principles underlying the toy known as the gyroscope. This amazing device appears to have been invented some time in the eighteenth century. It was studied scientifically by Foucault, a French physicist, about 1851. The gyroscope is a wheel with a heavy rim, so mounted that it can spin very rapidly on its axis. When friction is reduced to a minimum and the method of mounting and suspending eliminates restraint by other objects or external forces, the gyroscope tends to point its axis in a definite direction and to return to that direction if disturbed. Possibilities of great usefulness were perceived. By diligent, tedious, and expensive investigation and great ingenuity, overcoming many obstacles, Mr. Sperry skilfully combined electrical and mechanical elements into successful gyroscopic compasses and stabilizers for ships and airplanes.

The gyroscopic compass was completed in 1910 and was first tried out on the United States Battleship *Delaware* at the Brooklyn Navy Yard. Soon after this it was adopted by the U. S. Navy and during the War it was used in the allied navies and subsequently by more than sixty steamship lines. In 1913 the gyroscopic stabilizer for ships appeared. The following year Mr. Sperry entered the field of aeronautics, and on June 14, 1914, his airplane stabilizer was awarded a first prize of 50,000 francs by the French government in a contest for safety devices for airplanes. The winning machine was piloted by the inventor's son, Lawrence B. Sperry.

These inventions have been great contributions to safety and comfort of navigation of the seas and the air. In some respects they are the most distinctive productions of a remarkably prolific inventor.

Another of Mr. Sperry's inventions is a device for detecting flaws in steel rails. The detector is mounted upon a car which runs along the track at the rate of 6 to 8 m.p.h. Any flaw in the rail is detected, recorded in ink on a moving chart, and its location automatically marked on the rail with white paint.

Mr. Sperry possessed a rare combination of business and inventive ability. Prior to 1910 six companies had been founded to manufacture his inventions with an aggregate annual business in excess of five million dollars. In 1910 he organized the Sperry Gyroscope Company, New York, to manufacture the gyrocompass, ship and airplane stabilizers, high-intensity searchlights, fire-control apparatus, internal-combustion engines, and other products invented by him. In January, 1929, this company was sold to the North American Aviation Company. At the time of death he was chairman of the board of the Sperry Products, Inc., successor to the Sperry Development Company and the Sperry Rail Service Corporation.

Mr. Sperry obtained more than four hundred patents. For nearly fifty years he was an unusually productive worker in a surprisingly wide area of science and engineering. Many honors were conferred upon him for his achievements. In 1914, as already noted, he was awarded the first prize of the Aero Club of France for his airplane stabilizer. In that year he also received the John Scott Legacy Medal and Premium awarded by the Franklin Institute. Other awards include the Collier Trophy in 1915 and 1916; the John Fritz Medal, 1927; the Holley Medal, 1927; the Elbert H. Gary Medal of the American Iron and Steel Institute, 1929; the Elliott Cresson Medal of the Franklin Insitute, 1929; two decorations from the Emperor

of Japan, the Order of the Rising Sun and the Order of the Sacred Treasure; two decorations from the last Czar of Russia; and the Grand Prize, Panama Exposition.

Mr. Sperry was a member of the United States Naval Consulting Board and chairman of the Division of Engineering and Industrial Research of the National Research Council. He was a founder member of the American Institute of Electrical Engineers and the American Electrochemical Society; a life member of the A.S.M.E., which he joined in 1910 and which he served as president in 1928-1929; and past-president of the New York Electrical Society. He was also a member of the American Chemical Society, the Society of Naval Architects and Marine Engineers, Society of Automotive Engineers, American Petroleum Institute, American Association for the Advancement of Science, National Academy of Sciences, Edison Pioneers, National Aeronautic Association, Franklin Institute, and other technical and scientific organizations in this country. He was an honorary member of the Japanese Society of Mechanical Engineers, the Japanese Society of Naval Architects, the Japanese Society of Electrical Engineers, the Illuminating Engineering Society of Japan, and the Engineering Association of Hawaii. He was a member of the Engineers' Club of New York and numerous other social organizations as well.

Mr. Sperry has been credited with having originated the World Engineering Congress in Japan in 1929. He was elected chairman of the American Committee, of which President Hoover was honorary chairman. At the Congress he was elected an honorary vice-president and, as leader of the American delegation, took a very active part in the program.

Stevens Institute of Technology and Lehigh University conferred the degree of Doctor of Engineering upon Mr. Sperry and Northwestern University the degree of Doctor of Science.

Mr. Sperry was married in 1887 to Miss Zula A. Goodman, recently deceased, of Chicago. He is survived by his daughter, Helen Marguerite (Mrs. Robert Brooke Lea), his sons, Edward Goodman and Elmer A. Sperry, Jr., and five grandchildren. Another son, Lawrence Burst, lost his life flying over the English Channel in 1923 in a plane of his own design.

JOHN STRACHAN

John Strachan was born at Govan, Glasgow, Scotland, on July 24, 1872, and belonged to one of the most prominent families connected with shipbuilding in Scotland. Following the completion of grammar school, he acquired a technical education at the Andersonian Institute, Glasgow, of which he was a graduate. He next served a six years' apprenticeship with Dunsmuir & Jackson, Govan, Glasgow, four years of which were spent in the shops and the last two years in the drawing office. For the next two years he worked in the engine drawing office of Alex. Stephen & Sons, Linthouse, Glasgow.

Mr. Strachan's sea experience comprised fifteen year's service with the Allan and State Line, Glasgow, Scotland, during which time he served in all grades from junior to chief engineer, and the latter part of the time as assistant superintendent engineer, and five years with the United Fruit Company as chief engineer. During his service with the United Fruit Company he spent the greater portion of the time at Belfast, Ireland, supervising the construction of vessels for the passenger and fruit trade.

In 1913 Mr. Strachan left the United Fruit Company to join the Babcock & Wilcox Company, with whom he remained four years doing testing and experimental work on coal, pulverized coal, and oil fuel. For some time he was in charge of the shell shop at Barberton, Ohio, which was engaged in making 9.2 shells for the British government. When the United States entered the World War Mr. Strachan left the Babcock & Wilcox Company and joined the American International Shipbuilding Corporation, Hog Island, Pa., where he served two and a half years as general superintendent of machinery installation and outfitting, and in charge of all floating equipment.

In 1919 he joined the International Products Steamship Company as operating manager and during his connection with that company had charge of the building of two refrigerator ships for the carrying of frozen meats. He spent a large portion of his time while with this company in Buenos Aires and Paraguay, South America.

In 1922, on his return from South America, he joined A. H. Bull & Company as operating manager, and in 1924 he became connected with the Black Diamond Steamship Corporation in a similar capacity.

In 1925 Mr. Strachan left the Black Diamond Company to practice as a consulting engineer and surveyor, in which business he was still actively engaged at the time of his death.

He became a member of the A.S.M.E. in 1920. He was also a member of the Society of Naval Architects and Marine Engineers. His death occurred on February 2, 1930.

JOHN T. TAYLOR

John T. Taylor, who had been a member of the A.S.M.E. since 1891, was born in England on July 31, 1855. At the age of fifteen he began an apprenticeship as machinist, following the completion of which he worked as a journeyman until 1878. He had six years' experience as a locomotive engineer and six as chief engineer for W. & J. Sloane, New York, N. Y. He attended Cooper Institute, from which he was graduated in 1890, subsequent to which he did consulting work for the Oldham Mills Company. For many years he had been superintendent and building manager for Horace S. Ely & Company, New York, N. Y.

Surviving Mr. Taylor is a daughter, Miss Alice Taylor, of New York.

WILLIAM MASON TOWLE

William Mason Towle, professor emeritus of industrial engineering, Clarkson College of Technology, Potsdam, N. Y., died suddenly at his home at Enosburg Falls, Vt., on October 21, 1930. He was a life member of the A.S.M.E., which he joined in 1887.

Professor Towle was born at Franklin, Vt., on December 21, 1851, the son of John Johnson and Mercy A. (Mason) Towle. He attended the normal school there and subsequently the Montpelier (Vt.) Seminary. He was graduated from Worcester Polytechnic Institute with a B.S. degree in mechanical engineering in 1877.

For some years following the completion of his college work Professor Towle engaged in the manufacture of sashes, doors, etc., as a partner in the firm of Manley & Towle in Enosburg Falls. In 1884 he went to Terre Haute, Ind., as superintendent of the Bramble Lock Works, and during the next two years was draftsman for the United Brass Company, Lorain, Ohio. He then became instructor in machine toolwork at Rose Polytechnic Institute at Terre Haute, where he remained until 1888. For the next year he was employed by the Buckeye Engine Company, Salem, Ohio, and the Straight Line Engine Company, Syracuse, N. Y.

Professor Towle returned to the teaching profession in 1889 as instructor in mechanical engineering and foreman of the machine shop at Sibley College, Cornell University, and with the exception of a year (1891-1892) as mechanical engineer for the Mansfield (Ohio) Machine Works, devoted the remainder of his active life to that profession. He was assistant professor in charge of shops at Pennsylvania State College from 1892 to 1902, associate professor in charge of shops at Smith College, Syracuse University, during the next two years, and from 1907 until his retirement in 1917 professor of industrial engineering at Clarkson.

Professor Towle was a Methodist Episcopalian. He belonged to the Society for the Promotion of Engineering Education, the Vermont Society of Engineers, the Vermont Historical Society, the Royal Society of Arts, and the Potsdam Club, and was a fellow of the American Association for the Advancement of Science.

CARL EDWARD TRUBE

Carl Edward Trube, who died on March 11, 1930, as the result of burns suffered during some experimental work, was born in New York, N. Y., on February 22, 1901. He attended the Horace Mann High School and Stevens Institute of Technology, from which he was graduated with an M.E. degree in 1922.

Following his graduation Mr. Trube was employed for a time at the Jersey City branch of the Mengel Company, in charge of the development and production of radio apparatus. Later he took up consulting work in New York and at Ossining, N. Y. He became a junior member of the A.S.M.E. in 1923.

CHARLES PRENTICE TURNER

Charles Prentice Turner, who died on October 25, 1930, was born at Oxford, N. Y., on March 30, 1862.

After his graduation from Oxford Academy he entered Lehigh University, from which he received a M.E. degree in 1889.

His first work was with the Cambria Steel Company, Johnstown, Pa., making physical tests of iron and steel, and doing drafting and general construction work until 1892. After a year as draftsman on engines and boilers for the Stearns Manufacturing Company, Erie, Pa., and about six months' work on special engine research for Professor J. F. Kline of Lehigh University, he returned to the steel industry as draftsman for the Johnson Company (now Lorain Steel Company) at Lorain, Ohio. In addition to drafting he made estimates and checks on the design of steel plants and mills.

In 1895 and 1896, and from 1897 to 1901 Mr. Turner wrote and edited textbooks for the International Correspondence School of Scranton, and was principal of its school of mechanical engineering.

In 1896 and 1897 he was employed by the Carnegie Steel Company, Braddock, Pa., as draftsman at the Edgar Thomson Works.

Mr. Turner severed his connection with the International School in 1901 to take charge of the construction of the Clairton Steel Works and furnaces, Clairton, Pa., for the Garrett-Cromwell Engineering Company of Cleveland, Ohio. After completing this job he installed furnaces at the Delray, Michigan, plant, and was chief draftsman for the company's furnaces and steel works.

From 1903 to 1906 Mr. Turner was associated with the National Tube Company of McKeesport, Pa., in charge of the design and construction of new rolling mills, power plants, etc., for the company.

Mr. Turner went to the Steelton, Pa., plant of the Pennsylvania Steel Company in 1906, and his first duties were the design and construction of a new open-hearth unit of five 70-ton furnaces. As soon as the work was well under way at Steelton, he was transferred temporarily to the plant of the Maryland Steel Company at Sparrow's Point, Md., which was under the same financial control as the Pennsylvania Steel Company, to start the design and construction of the first open-hearth plant there.

In 1908 he was made chief engineer of the Steelton plant and continued in this capacity until the latter part of 1926, although in 1916 the ownership of the plant had been acquired by the Bethlehem Steel Company.

In 1926 Mr. Turner was transferred to the central office of the Bethlehem Steel Company at Bethlehem as an engineer in the development and research department, a position for which his long and intimate contact with the steel plant's operations eminently qualified him. He continued in this capacity until ill health compelled his retirement in 1929.

During his long period of service as chief engineer of the Steelton plant the program of improvements was continued beyond the construction of the open-hearth unit, the engineering of which first drew him there. In all the successive development and reconstruction of coke ovens, blast furnaces, rolling mill, and additional departments, Mr. Turner had a large share of the responsibility.

Mr. Turner became a member of the A.S.M.E. in 1912. He is survived by his widow, Laura V. Turner.

GEORGE CHRISTIAN UGGLA

George Christian Uggla died on January 12, 1930, as the result of an automobile accident a few days before.

Mr. Uggla was born at Westerias, Sweden, on May 26, 1885, and secured his education in that country. For a time he was connected with the Atlas Machine Company in Sweden, in machine shop work, and also had some experience in shipbuilding and in engine operation at sea. He came to the United States in 1905 and had been naturalized. His first position here was with the Midland Steel Company, on general machine work and as erecting and steam engineer in charge of the power house.

Since 1907, Mr. Uggla had been connected with the Seneca Iron & Steel Co., of Buffalo, N. Y., with the exception of from 1927 to 1929, when he was with the Michigan Steel Company. He served the Seneca company in various positions, and at the time of his death was its chief engineer.

Mr. Uggla became a member of the A.S.M.E. in 1927.

VERNER R. VELANDER

Verner R. Velander was born at Stanton, Iowa, on May 16, 1888. After completing high school he entered Iowa State College, at Ames, Iowa, from which he was graduated in 1909.

For the first year following his graduation, he was employed by the Crane Company of Chicago, as machine hand and foreman in the coupling department. He then spent three years with the Underfeed Stoker Company of America, at Chicago, two and a half years as draftsman of forced draft systems and boiler settings. From 1913 to 1914 he was working on the designing of boiler settings, piping systems, etc., for power stations for Sargent & Lundy of Chicago. During the next year he was responsible for the field inventory of mechanical equipment in connection with buildings in Detroit, as an employee of the Detroit United Railways. Subsequently for a short time he did similar work for the Public Service Corporation of Northern Illinois, in the employ of Sanderson & Porter. In 1916 Mr. Velander became associated with the Gas Machinery Company of Cleveland, Ohio, as a designer of mechanical equipment and structures for gas plants. After two years, he resigned this position to take charge of the drawing room of the Willis E. Holloway Co., Cleveland, Ohio, but left this company shortly to become connected with the Marion Machine Foundry & Supply Co., of Scottdale, Pa. His work for the latter firm included the design of coal handling machinery, crushing equipment, and other machinery. About 1924 Mr. Velander went to Pittsburgh, Pa., as district representative of the Stearns Conveyor Company. In 1926 and 1927 he was connected with the United States Arsenal in that city. He then removed to Chicago, where he founded the Verner Steel Products Company, with which he was identified at the time of his death.

Mr. Velander's death occurred at Chicago on May 22, 1930. He had been an associate member of the A.S.M.E. since 1921. He also belonged to the Swedish Engineers' Society of Chicago, Ill.

CHARLES MARSHALL WALES

Charles Marshall Wales, New York representative of the Wheeling Mold & Foundry Co., died of pneumonia at his home in Englewood, N. J., on November 1, 1930.

Mr. Wales was born at Elkhorn, Wis., on May 2, 1862, the son of Charles and Eliza A. (Crandall) Wales. After his graduation in 1885 from the University of Wisconsin, with a B.M.E. degree, he worked as a machinist in Providence, R. I., and Hartford, Conn., for Thurston, Stearns & Co., the Waterhouse Electric & Mfg. Co., and the Paige Typesetter Company until 1866. He then went to Cleveland as a designer and draftsman for the Prospect Machine & Engine Co. Following a year with this company, he became associated with the Cleveland City Forge & Iron Co. He designed and superintended the construction of furnaces and machinery at the Cleveland office for several years, following which he was made manager of the New York office of the company, a position which he retained until his death. In addition to his work as representative of the Wheeling Company and the Cleveland Forge Company, Mr. Wales engaged in consulting engineering.

Mr. Wales became a member of the A.S.M.E. in 1890. He also belonged to the Society of Naval Architects and Marine Engineers. For more than twelve years he was treasurer of the Engineers' Club (New York) and a member of its board of governors for nearly thirty years. He belonged to the New England Historical and Genealogical Society, the Western University Club, and the Knickerbocker Country Club. For more than twenty years he had belonged to the first Panel Sheriff Jury of New York.

Surviving Mr. Wales are his widow, Mrs. Catherine M. (Gillet) Wales, whom he married in 1894, and three daughters, Mrs. Roland B. Haines, Mrs. Walt Thomas, and Miss Elisabeth Crandall Wales.

CHARLES BOSS FRANKLIN WALLER

Charles Boss Franklin Waller, the son of William Henry Herron and Harriet Boss Waller, was born at Drifton, Pa., October 14, 1868.

His early education was obtained at the old Episcopal Academy in Philadelphia. After graduation he entered commercial life, first with the Pennsylvania Railroad and later with his father in the stock brokerage firm of W. H. H. Waller & Co. His inclinations however, were toward things mechanical, so leaving his father he studied engineering and its associated lines, taking a night course at the Franklin Institute and later the Scranton Course. In 1901 he entered the employ of the City of Philadelphia, in the Bureau of Water, where he remained until his death on January 22, 1930.

His long experience in testing boilers and pumping engines made him a valued employee, and for years he was responsible for the efficiency and upkeep of the entire water pumping system of the city.

He became an associate member of the A.S.M.E. in 1917 and also belonged to the Engineers and West Philadelphia Clubs.

JAMES T. WALLIS

James T. Wallis, associated for nearly forty years with the motive power department of the Pennsylvania Railroad and since 1927 assistant vice-president in charge of operation, died at his home in Philadelphia, on November 7, 1930.

Mr. Wallis was born in New Orleans, La., on June 11, 1868, and attended the University of Louisiana, Georgetown College, and Stevens Institute of Technology, from which he received an M.E. degree in 1891. The same year he began his service with the Pennsylvania Railroad as an apprentice in the West Philadelphia shops, and after a year's experience as superintendent of the Altoona Manufacturing Company, Altoona, Pa., returned to the drafting room of the Pennsylvania. For a time he was assistant road foreman of the Maryland Division of the P. W. & B. Railroad, then assistant master mechanic of the Meadows Shops of the P. R. R., and of its Altoona Shops, and master mechanic of the Baltimore Shops. For several years he was superintendent of motive power of the Erie Division and Northern Central Railway.

He became superintendent of the West Jersey & Seashore Railroad in 1911 and in the following year was made general superintendent of motive power of the Pennsylvania Railroad, with headquarters at

Altoona. Nine years later he was promoted to be chief of motive power with supervision over the power department of the entire system. He was in direct charge of the locomotive and car shops at Altoona and became widely known in the design and construction of railway cars and locomotives.

Mr. Wallis was a trustee of The Pennsylvania State College from 1913 to 1922. He also was interested in and cooperated with instruction in railroad mechanical engineering through tests conducted jointly by the Pennsylvania Railroad and The Pennsylvania State College.

Mr. Wallis became a member of the A.S.M.E. in 1901 and had served in its committee work on iron and steel.

HAROLD ASHLEY WELCOME

Harold Ashley Welcome, general manager of the American Mason Safety Tread Company, Lowell, Mass., died on October 27, 1930.

Mr. Welcome was born at Lowell, Mass., on March 26, 1894. He attended the Lowell High School and secured his training in mechanical drawing and machine shop practice at the Lowell Textile Institute, where he attended evening classes for five years. From 1912 to 1915, Mr. Lowell was shop foreman at the Saco-Lowell Shops. During the next five years he was connected with the U. S. Cartridge Co. in a similar capacity. He was in charge of the purchasing and testing of tool steel for the company at three different plants.

Mr. Welcome became identified with the American Mason Safety Tread Company as factory superintendent and mechanical engineer in 1920, and was made its general manager in 1922. He was in charge of factory production and sales, covering branch offices throughout the United States, Canada, and other countries. He devoted considerable time also to the experimental and patent departments of the company.

Mr. Welcome became an associate member of the A.S.M.E. in 1925 and was promoted to full membership three years later. He also belonged to the American Society of Safety Engineers and the Society of American Military Engineers.

OTTO H. L. WERNICKE

Otto H. L. Wernicke, president of Wernicke Engineers, Inc., Pensacola, Fla., was born in Calumet County, Wis., on June 18, 1862, the son of Carl F. G. and Sophia (Fricke) Wernicke.

His first employment was with O. C. Steenburg, manufacturers of sashes and doors, Fond du Lac, Wis., and the Nobridge Foundry of Fond du Lac. From 1881 to 1892 he was employed by Altman Miller & Co., manufacturers of harvesters and threshers, also the McCormick Harvester Company of Chicago, as well as by the Singer Sewing Machine Company, of New Brunswick, N. J. He entered the furniture manufacturing business in 1893 as a member of the firm of Wernicke Company at Minneapolis, Minn., and Grand Rapids, Mich. Among other concerns with which he was connected during the remainder of his life, serving as an executive, were the Globe Wernicke Company of Cincinnati, Ohio, the Wernicke Hatcher Laboratories, the Wernicke Hatcher Pump Company, the Wernicke Timber Land Company, the Wernicke Chemical Company, the Wernicke Mariner Company, the Pensacola Tar and Turpentine Co., and the Macey Company of Grand Rapids, Mich. He invented and developed the Wernicke record and business systems, sectional book cases and furniture, gas engines, air compressors, pumps, safes, kilns, sawing machinery, and other articles in the wood, metal, and chemical industries. He also contributed articles on subjects in these fields to the scientific and trade press.

Mr. Wernicke had served as a member of the Michigan National Guard, was chairman of the Michigan State Penology Commission from 1911 to 1917, and was a collaborator in the U. S. Forest Service. He became an associate member of the A.S.M.E. in 1918. He also belonged to the National Association of Manufacturers, the Furniture Association, the Florida Engineering Society, and the Masonic fraternity, as well as to a large number of clubs.

Mr. Wernicke married Loula Abbey in 1889, and is survived by her and a son, Julius F. Wernicke.

HAROLD WILSON WIKLE

Harold Wilson Wikle died at a private hospital in Atlanta, Ga., on April 24, 1930, after a major operation. Mr. Wikle was born in Atlanta, on February 15, 1902, the son of Mr. and Mrs. J. T. Wikle. He was a graduate with a B.S. degree in Mechanical Engineering from the Georgia School of Technology, Class of 1922. Technical experience which he had secured during summer vacations in the boiler room and power house of the Fulton Bag & Cotton Mills of Atlanta, where his father was chief engineer, was supplemented by the factory test course of the General Electric Company at Schenectady, N. Y., and Lynn, Mass., which he completed in December, 1923. Since that time he had been connected with the Southeastern District of the General Electric Company, and at the time of his death was one of its most capable and promising industrial salesmen.

Mr. Wikle became a junior member of the A.S.M.E. in 1924, and was also a member of the American Institute of Electrical Engineers. His widow, Helen (Macon) Wikle, survives him.

WILLIAM WILKE

William Wilke, whose death occurred on April 4, 1930, was born in Darmstadt, Germany, on September 9, 1855, the son of William and Charlotte Catherine (Seippel) Wilke. His father, who resided in the United States in 1848-1849, was a manufacturer of machine tools and special machinery in Darmstadt; and his mother was a daughter of John Seippel of Darmstadt, who came to Baltimore, Md., in 1845.

William Wilke attended the preparatory schools of his native city, served an apprenticeship of two years (1869–1871) in his father's shop, and was graduated with an M.E. degree at the Darmstadt Engineering College in 1877.

Immediately after his graduation he entered the employ of the Imperial Railways of Germany. He came to the United States in 1881 and for five years was assistant chief engineer of the Midvale Steel Company, Philadelphia, Pa. In this position he made the acquaintance of Frederick Winslow Taylor, who became his intimate friend, and to whom he gave valuable assistance in research work, particularly in perfecting the art of cutting metals.

During the years 1886–1893, Mr. Wilke was chief engineer of the Gray's Ferry Chemical Works, owned at that time by Harrison Bros. & Co., Philadelphia (now owned by the du Pont de Nemours Company) devoting his attention principally to construction work, remodeling antiquated chemical works, and improving chemical processes. Since 1893 he had an extensive practice as a consulting and construction engineer.

His principal contributions to the American chemical industry were the introduction into the United States in 1902 of the first Mannheim sulphur-trioxide process and the first Mannheim salt cake furnace and hydrochloric acid process; the design, construction, and inauguration of some of the largest fertilizer and sulphuric acid plants in the western hemisphere, as well as the development of new processes for the manufacture of white lead and lead oxide.

Mr. Wilke's white lead process consists in the reduction of metallic lead to a very fine powder which is charged into revolving cylinders, in which it is brought into intimate contact with acetic acid, steam or water vapors, and carbonic acid gas and transformed into carbonate of lead or white lead within seven days, whereas in the most prevalent system it requires 100 days. This idea had been tried in a similar crude way by the Adams White Lead Company, Baltimore, Md., in 1871–1880, and by Harrison Brothers in Philadelphia for more than ten years until Mr. Wilke developed the processes for the latter company in 1886, producing a capacity of 30,000 tons of white lead of the best quality within five years. The lead oxide process is similar and is carried out in various types of mechanical furnaces.

During the years 1886–1893, he superintended the reconstruction of the entire works of Harrison Bros. & Co., building twelve new factories for the manufacture of alum, acetic acid, white lead, lead oxide, nitric, muriatic and sulphuric acids, color making and grinding, varnish and oil treating, and other departments of chemical manufacture.

In 1893 he built the large sulphuric-acid and fertilizer plant at Pinner's Point, Va., and played an important part in organizing the Virginia & Carolina Chemical Co. In later years he built fertilizer and sulphuric acid plants for the Richmond Guano Company and the Phosphate Mining Company of Savannah, Ga., the large sulphuric acid plants for the American Smelting & Refining Co. at Garfield, Utah, and extensive plants for the Standard Oil Company, Richmond, Calif., the Dupont Powder Company, Pinola, Calif., the Pennsylvania Salt Manufacturing Company, Natrona, Pa., the Naugatuck Chemical Company, Naugatuck, Conn., the Merrimac Chemical Company and the Cochran Chemical Company, Boston, Mass., the Butterworth-Judson Company, Newark, N. J., the McDougall White Lead Plant and the Contract-Process Company, Buffalo, N. Y., and with his sons erected a large lead oxide plant for the Metals Refining Company, Inc., Hammond, Ind.

During the World War, Mr. Wilke rendered important service to the Government in inspecting factories and preparing exhaustive reports on their condition and industrial possibilities.

He became a member of the A.S.M.E. in 1893 and also belonged to the American Electro-Chemical Society, the American Institute of Mining and Metallurgical Engineers, the Society of American

Military Engineers, the Society of Chemical Industry of England, and the Verein deutscher Ingenieure of Germany. He was a 32nd degree Mason and a member of the University Club of Buffalo, N. Y., where he resided for many years. Mr. Wilke was twice married. His first wife, Catherine (Nax) Wilke, died in 1895, leaving three children, William Lewis, Erwin L., and Charlotte Wilke. In 1896 he married Mary Nax, sister of his first wife, and is survived by her and their son, Henry Phillip Wilke, as well as by his other children.

JOHN T. WILKIN

John T. Wilkin, president of The Connersville Blower Company, died at his home in Connersville, Ind., on December 27, 1930, of paralysis of the heart.

He was born on July 29, 1863, at Danville, Ind., the son of William and Susan Wilkin. He received his early education in the Danville and Plainfield schools and was graduated from the Rose Polytechnic Institute with a B.S. degree in 1886. He received an M.S. degree in 1893 and his M.E. two years later.

Mr. Wilkin went to Connersville in 1886 as draftsman for the P. H. & F. M. Roots company. He married Hortense Riley of Connersville in 1889.

A few years later Mr. Wilkin was instrumental in organizing The Connersville Blower Company. He was first chief engineer of the Blower Company, later vice-president, and upon the death of E. W. Ansted, became president, which position he occupied for more than ten years.

During his career with the Blower Company he was credited with a number of important inventions and perfections relating to his business and had recently completed a new gearing arrangement which is considered one of his most important inventions.

Mr. Wilkin became a member of the A.S.M.E. in 1898, and had a keen interest in its activities. He served as a member of its Publications Committee from 1921 to 1925.

Mr. Wilkin was also a member of the Franklin Institute and a charter member of the Old Colony Club and of the Columbia Club in Indianapolis.

He was a trustee of Western College for Women at Oxford, Ohio, and of the First M.E. Church of Connersville, and belonged to the Masonic fraternity.

D. CURTIS WILLIAMS

D. Curtis Williams, connected with the engineering department of the National Tube Company, Pittsburgh, Pa., for 28 years, died on February 27, 1930. Mr. Williams was born at Shaftsbury, Vt., on September 2, 1860, and attended Lehigh University and Stevens Institute of Technology.

His early experience was as draftsman and assistant superintendent in the steel mill of William Whitely, Springfield, Ohio, and as draftsman and assistant master mechanic in the Gautier Steel Department of the Cambria Iron Company, Johnstown, Pa.

Mr. Williams became a member of the A.S.M.E. in 1891. He also belonged to the Western Society of Engineers. He was a member of the First Unitarian Church of Pittsburgh. He is survived by his widow, Mrs. Ida M. Williams, and a daughter, Lorna N. Williams.

LAWRENCE PERRY WOLFE

Lawrence Perry Wolfe, whose death occurred on September 16, 1930, was born at Kittaning, Pa., on July 25, 1881. He completed the steam engineering course of the International Correspondence School and also studied at the Hays School of Combustion. From 1911 until his death, he was assistant chief engineer of the Covington Plant of the West Virginia Pulp & Paper Co. His main duties were those of promoting and maintaining efficiency in the production and use of steam and other power at this and other plants of the company, and he also conducted tests of boilers, furnaces, and other plant equipment. He designed an automatic flue gas collector and a system of cost accounting and record keeping, and also assisted in the design and construction of other furnace and stoker equipment.

Mr. Wolfe became an associate member of the A.S.M.E. in 1921.

EDWARD RANDOLPH WOOD, JR.

Edward Randolph Wood, Jr., who died in Paris, France, on March 5, 1930, was born at Philadelphia, Pa., on March 25, 1876, the son of Edward Randolph and Mary (Kneas) Wood. He was graduated from the Episcopal Academy in that city in 1893 and five years later secured his M.E. from Cornell University.

His first position was with the Camden Iron Works, Camden, N. J., and he remained in the employ of that company for some time, being promoted to the position of erecting engineer. From 1900 to 1914 he was engineering salesman and machinery sales manager for R. D. Wood & Co. of Philadelphia. Since 1914 he had been executor and trustee of the estate of Stuart Wood, president and treasurer of the Tampa Water Works Company, director of the Market Street National Bank, and president of the Cotiga Development Company.

Mr. Wood was commissioned a Captain of Field Artillery in 1917 and served with the 18th F. A. in the Second Battle of the Marne, St. Mihiel Salient, Argonne Forest, and Heights of the Meuse.

Mr. Wood was a life junior member of the A.S.M.E., which he joined in 1900. He also belonged to the Franklin Institute, American Academy of Natural Sciences, Iron and Steel Institute of Great Britain, American Society for Testing Materials, and a number of clubs in Philadelphia and New York.

WILLIAM HEAWORD WOOD

William Heaword Wood died at Media, Pa., on July 12, 1930. He was a native of England, having been born at Stockport, Cheshire, on November 26, 1844. He secured his early engineering training under his father, James Wood, a prominent engineer and millwright in England. After coming to the United States, where he later became a citizen, he worked for a time as draftsman for Ribon and March, Jersey City, N. J. In the early eighties he established an office in New York as a member of the firm of Wood and Richmond. At this time he designed and patented the first refrigerating and ice machinery in America. In 1885 he formed a partnership with Thomas Shipley, who had been connected with the firm of Wood and Richmond. Mr. Shipley, who later became well known in the refrigeration industry and was also a member of the Society, died about six months before Mr. Wood. Their partnership was dissolved in 1886 when Mr. Wood became connected with B. W. Payne & Sons of Elmira, N. Y., and also with Bement, Miles & Co., of Philadelphia.

In 1891 Mr. Wood established his own business at Media, Pa., as a hydraulic engineer, and designer and builder of special hydraulic machinery. He conducted this business until a few months before his death, when he sold it to the Reading Iron Company, which had previously built these machines according to his specifications.

Mr. Wood was the inventor of corrugated locomotive fire boxes and tube plates which several years ago were tried out by some of the largest railroads in the United States.

Mr. Wood became a member of the A.S.M.E. in 1889. He also belonged to the Western Railroad Club and the New York Railroad Club. Mr. Wood is survived by his widow, Bertha A. Wood, and a daughter, Miss Katharine H. Wood, of Media.

VOLLIE RICHARD YATES

Vollie Richard Yates, associate professor of mechanical engineering at the University of Vermont, Burlington, Vt., died of acute nephritis at the Mary Fletcher Hospital in that city on May 31, 1930.

He was born at Richford, Vt., on June 30, 1889, son of Richard and Flora (Dew) Yates. When he was six months old his parents moved to Fairfield, where he attended the local schools until he entered the St. Albans High School. He entered the University of Vermont in 1911, and received the degree of B.S. in mechanical engineering in 1915, winning Phi Beta Kappa honors.

Immediately after graduation he was made instructor in the department of mechanical engineering. In 1921 he was promoted to an assistant professorship in the same department and last year received a further promotion to an associate professorship. Since the death of Professor Edward Robinson in 1929 he was acting head of the department.

He was an untiring student of his subject. The summers of 1915 and 1917 were spent at the Jones & Lamson works in Springfield, acquiring practical experience. In 1925 he attended the summer school of the Westinghouse plant in Philadelphia, specializing in turbine design. The academic year 1926–1927 he spent at the University of Michigan, doing graduate work, principally in automotive and aeronautic engineering. He had acquired considerable proficiency in the mathematics and mechanics of turbine and aeroplane design. The summer of 1929 he spent at the S.P.E.E. School of Engineering at Purdue University, specializing in scientific management, a subject in which he was growing much interested.

Professor Yates might be truly called a born teacher, a calling which appealed to him very strongly. He was himself a thorough student and a master of his subject, and this, combined with a most likable personality and a deep personal interest in each student, always secured close attention and hearty cooperation from the class.

He became a member of the A.S.M.E. in 1923 and also belonged

to the Phi Mu Delta Fraternity, the Vermont Society of Engineers, the Society for the Promotion of Engineering Education. He was a communicant of the First Church of Burlington.

JOHN JAMES YORK

John James York, general works manager of the St. Lawrence Sugar Refineries, Ltd., Montreal, Canada, died on April 10, 1930. He is survived by a son, J. Aleck York, who is chief engineer of the company.

Mr. York was born at Lacadie in the Province of Quebec, on June 12, 1861. Through private tutorship and two years' study at the Council of Arts and Manufacturing he secured fundamental engineering training, and then served an apprenticeship in steam heating and ventilation.

All of his professional life from that time, with the exception of two years with The Garth Company, was devoted to the St. Lawrence Sugar Refining Company, now the St. Lawrence Sugar Refineries, Ltd. He designed and erected both buildings and machinery for the company, introducing new systems of heating feedwater, insulating underground steam lines, weighing and piling goods, etc. Mr. York had been a member of the A.S.M.E. since 1910.

LESLIE I. ZIEGLER

Leslie I. Ziegler died of heart disease on June 6, 1930, while returning to Indianapolis from a trip to Buffalo. Surviving him are three sisters and three brothers.

Mr. Ziegler was born at Sterling, Ohio, on September 22, 1864. He was with Millwright & Miller of Cincinnati, at Sterling, as apprentice from 1883 to 1891, and for the following year with the Bradford Mill Company, Cincinnati, Ohio, as superintendent of design and manufacturing of cereal machinery.

From 1900 to 1925, Mr. Ziegler was associated with the Nordyke & Marmon Co., at Indianapolis. For five years he was sales engineer of cereal milling machinery and for four years superintendent of installation plans. He then became general manager of the milling machinery department. Since his resignation from the company he had practiced as a consulting engineer.

Mr. Ziegler had been a member of the A.S.M.E. since 1914.

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West Lafayette	Library, Purdue University

Iowa

Ames	Iowa State College
Des Moines	Public Library
Iowa City	State University of Iowa

Kansas

Kansas City	Public Library, Huron Park
Lawrence	Library, University of Kansas
Manhattan	Kansas State Agricultural College
Wichita	Wichita City Library

Kentucky

Lexington	University of Kentucky
Louisville	Speed Scientific School
	University of Louisville

Louisiana

Baton Rouge	Louisiana State University
New Orleans	Howard Memorial Library
	Louisiana Engineering Society
	Public Library

Maine

Orono	University of Maine

Maryland

Annapolis	United States Naval Academy
Baltimore	Johns Hopkins University
	Engineers Club of Baltimore
	Public Library

Massachusetts

Boston	Northeastern University
	Boston Public Library
Cambridge	Massachusetts Institute of Technology
Fall River	Public Library
Lowell	Lowell Textile Institute
Lynn	Free Public Library
New Bedford	Free Public Library
Springfield	Springfield City Library
Tufts College	Tufts College
Worcester	Worcester Polytechnic Institute
	Free Public Library

Michigan

Ann Arbor	University of Michigan
Detroit	Public Library
	Cass Technical High School
	Highland Park Public Library
Flint	Public Library
Grand Rapids	Public Library
Houghton	Michigan College of Mining and Technology
Jackson	Public Library
Lansing	Michigan State College

Minnesota

Duluth	Public Library
Minneapolis	University of Minnesota
	Minneapolis Public Library (Engineering and Circulating Libraries)
St. Paul	James Jerome Hill Reference Library

Mississippi

Columbus	Mississippi Agricultural & Mechanical College

Missouri

Columbia	University of Missouri
Kansas City	Public Library
Rolla	Missouri School of Mines and Metallurgy

Missouri (Continued)

St. Louis	Engineers Club of St. Louis
	Public Library
	Washington University
	Mercantile Library

Montana

Bozeman	Montana State College

Nebraska

Lincoln	University of Nebraska
Omaha	Public Library

Nevada

Reno	University of Nevada Library

New Hampshire

Durham	University of New Hampshire

New Jersey

Bayonne	Free Public Library
Camden	Free Public Library
Elizabeth	Free Public Library
Hoboken	Stevens Institute of Technology
Jersey City	Free Public Library
Newark	Newark College of Engineering
	Free Public Library
New Brunswick	Rutgers University
Paterson	Free Public Library
Princeton	Princeton University
Trenton	Free Public Library

New York

Albany	New York State Library
Brooklyn	Polytechnic Institute
	Pratt Institute
	Brooklyn Public Library
Buffalo	The Grosvenor Library
	Engineering Society of Buffalo
	Buffalo Public Library
Ithaca	Cornell University
Jamaica, L. I.	Queens Borough Public Library
New York	Engineering Societies Library
	Public Library
	College of the City of New York
	Cooper Union
	Columbia University
	N. Y. University Library
Potsdam	Clarkson College of Technology
Rochester	Rochester Engineering Society
Schenectady	Union College
Syracuse	Syracuse University
	Public Library
Troy	Rensselaer Polytechnic Institute
Utica	Public Library
Yonkers	Public Library

North Carolina

Chapel Hill	University of North Carolina (Engineering Library)
Raleigh	North Carolina State College

North Dakota

Fargo	North Dakota State College
Grand Forks	University of North Dakota

Ohio

Ada	Ohio Northern University
Akron	Public Library
	University of Akron
Canton	Public Library
Cincinnati	University of Cincinnati
	Public Library
	Engineers Club of Cincinnati
Cleveland	Public Library
	Case School of Applied Science
	Cleveland Engineering Society
Columbus	State of Ohio Library
	Public Library
	Ohio State University
Dayton	Engineers Club of Dayton
Toledo	Public Library
	University of Toledo
Youngstown	Public Library

Oklahoma

Norman	Oklahoma University
Oklahoma City	Public Library
Stillwater	Oklahoma Agricultural and Mechanical College
Tulsa	Public Library

Oregon

Corvallis	Oregon State Agricultural College
Portland	Portland Library Association

Pennsylvania

Allentown	Free Library
Bethlehem	Lehigh University
Easton	Public Library
	Lafayette College
Erie	Public Library
Lewisburg	Bucknell University
Philadelphia	Engineers Club
	Drexel Institute
	University of Pennsylvania
	Franklin Institute
Pittsburgh	University of Pittsburgh
	Engineers' Society of Western Pennsylvania
	Carnegie Institute of Technology
	Carnegie Library (Schenley Park)
	Carnegie Free Library of Allegheny
Reading	Public Library
Scranton	Public Library
State College	Pennsylvania State College
Swarthmore	Swarthmore College
Villanova	Villanova College
Wilkes-Barre	Public Library

Porto Rico

Mayaguez	University of Porto Rico

Rhode Island

Kingston	Rhode Island State College
Providence	Brown University
	Providence Engineering Society
	Public Library

South Carolina

Clemson College	Library, Clemson College

Tennessee

Kingsport	Public Library
Knoxville	University of Tennessee
Memphis	Goodwin Institute
Nashville	Vanderbilt University

Texas

Austin	University of Texas
College Station	Agricultural & Mechanical College of Texas
Dallas	Public Library
El Paso	Public Library
Fort Worth	Carnegie Public Library
Houston	Rice Institute
	Public Library
Lubbock	Texas Technological College (School of Engineering)
San Antonio	Carnegie Library

Utah

Salt Lake City	University of Utah
	Public Library

Vermont

Burlington	University of Vermont

Virginia

Blacksburg	Virginia Polytechnic Institute
Charlottesville	University of Virginia
Norfolk	Carnegie Public Library
Richmond	Virginia State Library

Washington

Pullman	State College of Washington
Seattle	Public Library
	Engineers Club
	University of Washington
Spokane	Public Library
Tacoma	Public Library

West Virginia
- Morgantown — West Virginia University

Wisconsin
- Madison — Library, University of Wisconsin
- Milwaukee — Public Library
  - Board of Industrial Education, Vocational School Library
  - Marquette University

Wyoming
- Laramie — Wyoming University

OTHER COUNTRIES

Argentine
- Buenos Aires — Biblioteca de la Sociedad Cientifica

Australia
- Adelaide — Public Library of Adelaide
- Melbourne — Public Library of Victoria
- Perth — University of Western Australia Library
- Sydney — Public Library, N. S. W., Sydney

Brazil
- Rio de Janeiro — Bibliotheca da Escola Polytechnica
  - Bibliotheca Nacional
- Sao Paulo — Bibliotheca da Escola Polytechnica

Canada
- Montreal — McGill University
  - Engineering Institute of Canada
- Toronto — University of Toronto, Library

Chile
- Santiago — Universidad de Chile, Facultad de Ciencias Fisicas y Matematicas (Engrg. School)

Czechoslovakia
- Prague — Masarykova Akademie Prace
  - Association of Czechoslovak Engineers

Danzig Free City — Bibliothek der Technischen Hochschule

Denmark
- Copenhagen — The Royal Technical College

England
- Birmingham — Birmingham Public Libraries
- Bristol — University of Bristol
- Cambridge — University of Cambridge
- Leeds — University of Leeds
- Liverpool — Public Library of Liverpool
- London — City & Guild Engineering College
  - Institution of Mechanical Engineers
  - Institution of Civil Engineers
  - Institution of Electrical Engineers
  - The Royal Aeronautical Society
- Manchester — Manchester Public Libraries (Reference Library)
- Oxford — University of Oxford
- Newcastle-upon-Tyne — The North East Coast Institution of Engineers and Shipbuilders

Wales
- Cardiff — Cardiff Public Library

France
- Lyons — University of Lyons
- Paris — École Nationales des Arts et Metiers
  - École Supérieure de Mécanique et d'Aeronautique
  - École Centrale des Arts et Manufactures de Paris
  - Société des Ingénieurs Civils de France

Germany
- Berlin — Bücherei des Vereines deutscher Ingenieure
  - Bibliothek der Technischen Hochschule

Germany (Continued)
- Breslau — Bibliothek der Technischen Hochschule
- Cologne — Universitäts- und Stadtbibliothek
- Dresden — Bibliothek der Technischen Hochschule
- Düsseldorf — Bücherei des Vereins deutscher Eisenhüttenleute
- Frankfort — Technische Zentralbibliothek
- Hamburg — Bibliothek der Technischen Staatslehranstalten
- Hanover — Bibliothek der Technischen Hochschule
- Karlsruhe — Bibliothek der Technischen Hochschule
- Leipsic — Stadtbibliothek
- Munich — Bibliothek der Technischen Hochschule
  - Bibliothek des Deutschen Museums
- Stuttgart — Bibliothek der Technischen Hochschule

Holland
- Amsterdam — Koninklyke Akademie von Wetenschappen
- The Hague — Koninklijk Instituut van Ingenieurs
- Rotterdam — National Technisch-Schlep-Caartkundig Museum

India
- Bangalore — Mysore Engineers Association
- Calcutta — Bengal Engineering College
- Poona — Poona College of Engineering
- Rangoon — University of Rangoon

Ireland
- Belfast — Queen's University of Belfast

Italy
- Milan — Biblioteca della R. Scuola d'Ingegneria
  - Comitato Autonomo per l'Esame della Invenzioni
- Naples — Biblioteca della R. Scuola d'Ingegneria
- Rome — Biblioteca della R. Scuola d'Ingegneria
  - Consiglio Nazionale delle Ricerche presso il Ministero della Educazione Nazionale
- Turin — Biblioteca della R. Scuola d'Ingegneria

Japan
- Kobe — Kobe Technical College
- Tokyo — Imperial University Library
  - The Society of Mechanical Engineers
- Yokohama — Library of Yokohama

Mexico
- Mexico City — Asociacion de Ingenieros y Arquitectos de Mexico
  - Library of the Escuela de Ingenieros Mecanicos y Electricistas

Norway
- Oslo — Universitetsbibliothek den Polytekniska Forening

Poland
- Warsaw — Bibljoteka Publicazna

Portugal
- Lisbon — Institute Superior Technico

Roumania
- Bucharest — Scoala Polytechnica din Bucharest

Scotland
- Glasgow — Royal Technical College
  - Mitchell Library

South Africa
- Johannesburg — South African Institute of Engineers

Sweden
- Stockholm — Kungl. Tekniska Hogskolan
  - Svenska Teknologföreninger
- Gothenburg — Chalmers Tekniska Institut

Turkey
- Constantinople — Robert College

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